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Determining methodologies for estimating the value product of water used for irrigation with application to selected cases

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by

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I. INTRODUCTION

A. The Problem of Water Allocation

The general objective of this study is to further our understanding of methodology appropriate to estimating value product of water in Iowa, particularly in regard to irrigation. By adding to our knowledge of water productivity, more consideration can be given to the water allocation process.

In the past, water has been treated largely as a free good. Water allocation has primarily been associated with land ownership rights. In the 31 Eastern contiguous states, the primary institution governing water allocation has been the riparian system (5). Any landholder owning land adjacent to a water course has been granted riparian rights to that body of water. Riparian rights also applied to land overlying a ". . . clearly defined underground water course . . ." (15). The doctrine governing riparian rights was that the landowner could use water but not use it up. In practice, this meant that a riparian owner could use all the water needed for domestic use, including household use and watering livestock. Other uses, loosely termed "artificial" included industrial, irrigation and sewage disposal, which were permitted as long as they did not infringe upon domestic uses. Disputes have been settled in courts.

The riparian system was and remains the most important institution governing the allocation of water in the humid areas of Western Europe (5) and in the Eastern United States (5). It is an adequate, workable system when a surplus of good quality water exists. It is not equipped to deal with the problems caused by competition for scarce water supplies or the impairment of water quality. This is due to the fact that it contains no provision to allocate water to the highest value use. This system was used in Iowa until 1957 (15).

The second major form of water allocation used in the 17 contiguous Western States is the doctrine of prior appropriations (15). According to this doctrine, an owner of land adjoining or overlying a water source may, through prior use, claim all or part of the water, provided he can prove that the water will be used for a beneficial purpose. This doctrine has provided a workable method of water allocation, especially in areas with arid climates. The prior appropriations system has demonstrated its viability in these areas by having endured over a century in this nation without any major revisions (15). Its major drawback is similar to that which limits the riparian doctrine, namely its failure to allocate water so that the greatest net value product is obtained. In short, both of these traditional water rights institutions are too crude to be compatible with the multi-sector and multi-use demand for water in today's economy.

Knowledge of hydrology and the difficult problems associated with the many sources and qualities of water have greatly expanded in recent decades (18). Legal institutions sufficiently flexible to deal with these problems need to be developed to use more effectively this recently developed knowledge. This fact was recognized in 1957 when the State of Iowa modified the riparian system into the permit system under the state's revised water law (16).

The Iowa water permit system represents a hybrid mixture of concepts taken from the riparian system, the prior appropriations system and other sources. It reflects the needs of the climatic situation of Iowa, a transitional area between the humid East and the arid West. The centralized decision-making body responsible for all water allocation decisions (except withdrawals less than 5000 gallons per day for individuals and 100,000 gallons per day for municipalities) closely resembles the Western system. The protected flow concept resembles the major cannon of the riparian system, namely, to use water within limits but not to use all of it. Perhaps the chief attribute of the Iowa permit system is its flexibility. With minor legal changes it appears able to accommodate many uses and methods of water allocation.

None of these three systems has as yet embraced the vast body of economic theory, principles and methods available for water allocation. Indeed, it would be impossible to do so except on a very rudimentary level with regard to the riparian or prior appropriations doctrines. The flexibility of the permit system does permit the application of allocative criteria based on economic principles, but this has not been done thus far. Yet, this is the major objective of economics embracing the allocation of scarce resources among competing uses.

Only in recent decades has water allocation been the subject of economic analysis (5). In the past, areas where water was scarce tended to be underdeveloped. Another important factor which helped place water outside the realm of economic analysis is the "fugitive" nature of the resource (16). In addition, an apparent "institutional immunity" has kept water isolated from the price system (5). This concept will be explored later. Growing awareness of the importance of water scarcity is inviting economists to find ways of overcoming the traditional difficulties which have limited analysis. Investments in water projects have provided most of the impetus for economic studies. But even when little or no investments are planned, policymakers are finding that knowledge of the value of water in different uses is vital to planning water uses.

The preceding statement briefly introduces the situation in Iowa. The need for water allocation studies in Iowa is especially apparent during dry periods of the weather cycle. The current system performs well during wet periods, but runs into difficulties during drought cycles. Nevertheless, the long term trend is for increasing water use. Already in certain parts of the state it is more appropriate to consider water as a scarce good than as a free good. This situation is likely to become more prevalent in the future as demand for water increases. As this happens, economic analysis will become increasingly relevant to the legal, institutional, and technological factors influencing water use in Iowa.

In practice, the major roles of economics in Iowa's water use are 1) to identify uses and areas where competition for water is likely to occur; 2) to indicate the value of water associated with different uses to aid in allocation decisions; 3) to estimate the costs associated with different water uses; and 4) to analyze different policy alternatives.

In the case of water allocation, economic analysis can provide the marginal value prducts of water in different uses and the allocation plan which optimizes the net value product of water. These results can be achieved on a static level by analyzing each water use individually and by combining the generated coefficients in a linear program. Dynamic programs, input-output models, and goal programming may be useful for intertemporal problems and to take into account the "fugitive" nature of the water resource.

B. Objectives of Study

The objectives of this study are fivefold: 1) to develop a model for ascertaining the marginal value product of irrigation water; 2) to apply this model to eight selected farms in Northwest Iowa; 3) to evaluate the usefulness of the model and to determine data and procedural needs based upon its application to the selected farms; 4) to suggest kinds of recommendations for improved water allocation in Iowa based upon limited data and 5) to suggest further research needs. The first three objectives are quite closely related. The first objective is fundamental, while objectives 2 and 3 arise from the research in applying results of the first one.

Applications for irrigation permits continue to outstrip all other water use applications, constituting over 60% of permitted withdrawals for consumptive water use in Iowa (23). It is the only sizeable water use whose expansion is seriously questioned in policy analysis. With an understanding of the marginal value product of irrigation water, policy-makers can decide at which point the benefits begin to be outweighed by the costs of irrigation. When they feel such a point has been reached, they may take action to limit further irrigation. The marginal value product may also have valuable applications for water pricing.

The second objective is to apply the model to selected farms in Northwest Iowa. By applying the model to specific farms, the methodologies are tested. Information derived from further evaluation of the methodologies can be of value to potential irrigators. Very few studies have included a large number of years of weather data to predict irrigation yield increases. This approach could be beneficial to farmers considering the long term investment required in irrigation.

The third objective is to evaluate the usefulness of the model and to determine data and procedural needs. Applying the model to selected farms provides a check on its accuracy and applicability of the methods. In so doing, drawbacks inherent to the model as well as deficiencies in data and procedures are revealed. Especially important to any irrigation model is the need for accurate estimates of irrigation yield increases. There are many ways to approach this problem. Several of these methods will be examined in relation to field experimental results. The advantages and disadvantages of several methods will be examined in order to aid anyone trying to improve on the model or to apply one of these systems to another area.

The fourth objective is to suggest the nature of recommendations for improved water allocation in Iowa that may be developed from further application of the procedure. 1978 is a propitious time to suggest changes in the existing system because water problems are still in the forefront of issues important to legislators and the public as a result of the recent drought. There are several aspects of water policy in Iowa which could be improved upon, especially regarding irrigation.

The fifth objective is to suggest further research needs. Further research is crucial to optimizing Iowa's present and future water use. This study provides some estimates of the value product of irrigation water, but further studies are needed to provide more accurate estimates, especially for different soil types. Specific research needs are suggested.

Methods of Pursuing Objectives

The methods which will be used in this study include: 1) estimating procedures for yield increases from irrigation; 2) estimating techniques for the costs of irrigation; and

3) use of procedures for determining the net return per unit of water as more land is brought into irrigation. Accurate estimation of yield increases and of associated costs is essential in an economic study of irrigation. Consequently, this study is concerned with procedures for estimating yield increases and the associated costs of irrigation in Iowa. The twelve county crop reporting district of Northwest Iowa, encompassing Lyon, Osceola, Dickinson, Emmet, Sioux, O'Brien, Clay, Palo Alto, Plymouth, Cherokee, Buena Vista, and Pocahontas counties, has been selected for this analysis for several reasons. The problem of water allocation is and probably will remain more serious in this area than in other parts of the state (12). In addition, considerable irrigation from limited water sources is taking place in this area. Finally, the crop reporting district appears to constitute a useable unit for obtaining crop and weather data. This is because the National Oceanographic and Atmospheric Administration (NOAA), the Iowa Meteological Service and the Iowa Crop and Livestock Reporting Service all provide data for crop reporting districts. Crop reporting districts are among the only units of land for which compatible data from a variety of sources can be found.

The major principle followed in predicting yield increases under irrigation is the use of several years of climatic data. Too often, irrigation studies have been based on only a few years of experimental data (4, 8, 36). Computing yield increases on the basis of so few years ignores the stochastic element of climatic variations. In addition, results so derived may be extremely misleading if Thompson's hypothesis regarding the cyclical nature of drought cycles in the Midwest is accepted (43). Irrigation studies have followed periods of interest in irrigation which have corresponded to drought cycles.

In this study procedures for estimating yield increases from irrigation are based on two methods. The first uses 49 continuous years of weather data; the second uses 17 continuous years of weather data. In both cases, the number of years used represents the maximum time period for which the data were available. Both methods can be considered stochastic if the cyclical element of climatic occurrence is ignored. Neither method is strictly stochastic if the cyclical effect is considered. Past weather patterns represent the best prediction of future climatic conditions (43) and, barring a radical change in weather patterns, either of these time periods should be sufficient for the purposes of this study.

The second phase of the analysis involved methodologies for obtaining average yield increases in Northwest Iowa by selected soil types. In this section the actual yield increases were obtained from eight selected irrigators in Northwest Iowa and compared with the theoretical results.[1] Differences will be related to several characteristics of the soil being irrigated, as described in the soil survey. This procedure is admittedly crude, but it could be refined in future research with more funds, information and time.

In the third phase of the analysis, methodologies are listed for obtaining cost data for irrigation through application to available data. Costs are subtracted from the value products of predicted yield increases to determine net revenues from irrigation. The differences in the cost of irrigation on upland, as opposed to river bottom sites are also computed.

These results form the illustrative basis for generating a marginal value product curve as more acres are brought into irrigation in the study area. Deriving this curve requires considerably more data and research than can be supplied here. In particular, such a project should be interdisciplinary in nature, with agronomists, climatologists and economists all sharing their expertise to provide the best possible coefficients. It is hoped that this methodological study will motivate others to pursue

[1]Eight irrigators were selected for purposes of illustrating possible applications of the procedures.

this area of study, refine techniques and extend applications to a sample of irrigations from which representative results may be derived for soil areas of Iowa.

Finally, because optimizing water use requires equating marginal benefits with marginal costs accruing to society, a qualitative discussion of the societal costs involved in increasing water use in Iowa is included in Appendix A.

D. Organization of this Report

This introductory chapter includes a brief statement of the problem of water allocation, the objectives of the study and the methods of pursuing these objectives. Chapter II develops the model for achieving these objectives. The underlying economic theory basic to this model is presented. The sub-models which are used to generate coefficients are also developed. The third chapter illustrates an application of the model to water allocation problems in Iowa. The fourth chapter consists of the implications of these findings for water allocation methodologies for future research needs. A summary of results and the conclusions are presented in the last chapter.

II. DEVELOPMENT OF THE MODEL

A. The Reason for Using a Marginal Value Product Curve Model

The model of the study is the marginal value product (MVP) curve of irrigation water as more acres are brought into irrigation. This approach differs slightly from the usual derivation of the marginal value product of an input such as water. In the usual derivation, the marginal physical product is calculated with respect to infinitely small increments of water. By calculating the marginal value product of irrigation water as more acres are brought into irrigation, the amount of water applied per acre is considered fixed for a given area and year. The difference is basically one of unit size. Instead of considering infinitely small increments of water, the increment used represents the annual application per acre. The magnitude of this unit varies by area and year, but an average figure is 11 inches per year. This subject is discussed in detail in Chapter III.

The reason for using this approach is that the problem being confronted in this study is that of expanding irrigated acreage. The amount of water applied by the individual irrigator is determined chiefly by physical factors such as climatic conditions, soil moisture, and the nature of the irrigation equipment. Economic factors influencing this decision exist, but they are minor in view of the fact that the fixed costs of irrigation overshadow the variable costs (Table 2).

To summarize this section, this study deals with the expansion of irrigation on the extensive margin rather than the intensive margin. Though both problems are important, expansion on the extensive margin appears to be of more immediate relevance to the question of water allcoation in Iowa.

An advantage of the approach used is that the coefficients generated are more compatible with input-output analyses. Input-output theory assumes that a fixed amount of input is required to produce a given level of output. This assumption is not entirely met because the amount of irrigation water required varies from year to year. Despite this difference, the results of this study should provide useful data for an input-output analysis of water resources in Iowa.

B. Theoretical Considerations

This section starts with a discussion of traditional concepts in water economics. It is followed by a discussion of how the MVP curve for irrigation is related to the problem of water allocation in general. The theoretical section is completed with a discussion on measuring the benefits of water use. This serves as an introduction to the empirical methods used to derive the MVP curve.

The social cost of production has been introduced into this discussion as an explanatory aid. Ferguson and Gould (10, p. 181) define the social cost of producing commodity X as "the amount of commodity Y that must be sacrificed in order to use resources to produce X rather than Y." The definition of the marginal social cost follows easily from this quote. If commodity Y is defined sufficiently broadly to include the nonmonetary as well as the monetary goods of society, there emerges a more realistic framework for analyzing policy decisions regarding water use. The purpose is not to quantify or analyze these intangible factors; that is beyond the scope of this study, though methods for measuring such effects do exist. The purpose of mentioning the marginal social cost curve here is to avoid ignoring nonmonetary costs. The social cost concept provides a theoretical framework for describing some of the environmental problems caused by the overuse of water. A discussion of some of these problems is included in Appendix A.

The criteria for an optimizing solution requires that marginal benefits in all uses equal marginal costs in all uses (10). This can be written mathematically as follows:

$$MVP_1 = MVP_2 = \ldots = MVP_i = P_D\ i{+}1 = \ldots =$$

$$P_D\ i{+}n = MSC_1 = \ldots = MSC\ i{+}n$$

where:

MVP is the marginal value product in input uses of water 1...i

P_D is the demand price of water as a final product in uses i+1...i+n

MSC is the marginal social cost in water uses 1...i+n

This idealized water use situation does not exist in the real world. The actual water use situation in Iowa differs sharply from the theory because of several important reasons. These reasons are as follows: 1) the theory treats water as a homogeneous good; 2) temporal effects may cause the short run optimum to differ from the long run optimum solution; 3) there are institutional constraints associated with charging a price for water; and 4) costs to society tend to be elusive and difficult to quantity and therefore are often ignored.

The first point is perhaps the most important. Water is not a homogeneous good. There are important spatial, distributional, and quality differences in water supplies. In legal, technical, or economic terms there are differences between surface water and groundwater; between water from a surficial aquifer and a bedrock aquifer; between water in Eastern Iowa and Western Iowa. These effects may be reconciled through a positively sloped supply curve when dealing with a single water use for a single location. In other words, obtaining water of a suitable quality at a specific location is simply a matter of increasing cost. Because water allocation in Iowa is concerned with a wide range of water uses, locations and quality standards, the problem is immensely more difficult. Spatial differences suggest a regional approach to water allocation. Distributional and quality differences simply emphasize the care that must be taken if a model is to accurately represent the actual situation.

The second reason that the actual water use situation differs from the theory is the presence of temporal effects. Investments and policies leading to short term solutions may differ from the optimum long term solutions. Cycles of dry and wet weather require that any study concerning water use in Iowa be based on a sufficiently long period to accurately estimate water supply.

The third reason is that in this nation, water has largely been considered a free good. As a result of this, the institution of treating water as a free good has become firmly entrenched in water policy.

In general, a free good is characterized by the supply exceeding the demand within relevant quantity limits.

This situation is represented in Figure 1.

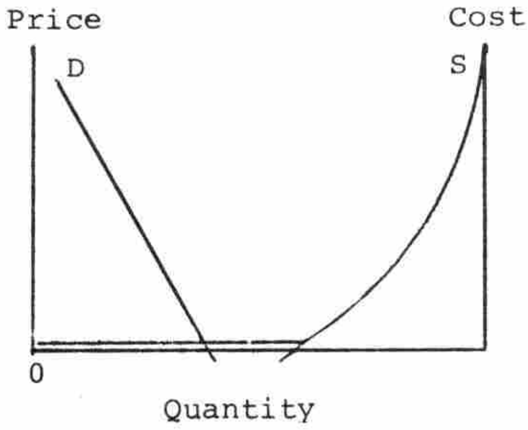

Figure 1. A free good

When this situation exists, consumers use all the water they want for free. Figure 1 indicates one of the fundamental reasons why water has become a free good, especially in humid areas. Regions which have traditionally had a surplus of high quality water may experience shortages in localized areas. Shortages may be due to pollution of some of the sources, to new, high consumption water uses, or to modern pumping technology which permits large and continuous water withdrawals. In such areas, water becomes a scarce good rather than a free good. This can be represented graphically by a shifting of demand to the right as shown in Figure 2.

There is not a positive equilibrium price, P_1. Water allocation problems will occur when the prevailing institution is unable to accommodate itsef to the changed

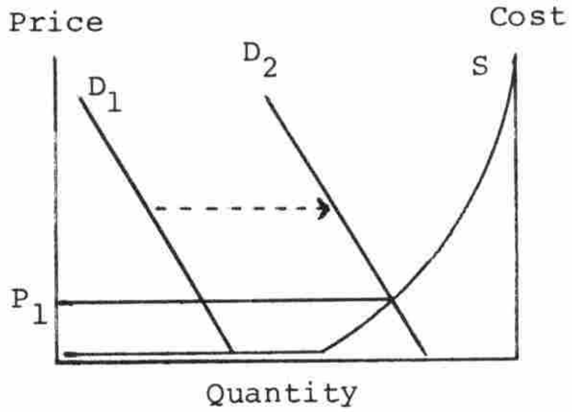

Figure 2. A shift in demand results in a positive price

situation and keeps the price at zero.[1] The major effect of this type of institutional inflexibility is the overuse of water, especially in low value uses.

In arid areas, where water has always been a scarce good, water availability has taken a positive price by being capitalized into land prices (6). A good domestic water supply source or a prior appropriation could increase the price of land in these areas.

For the purpose of resource allocation, capitalization into land prices is a poor substitute for a direct tax on

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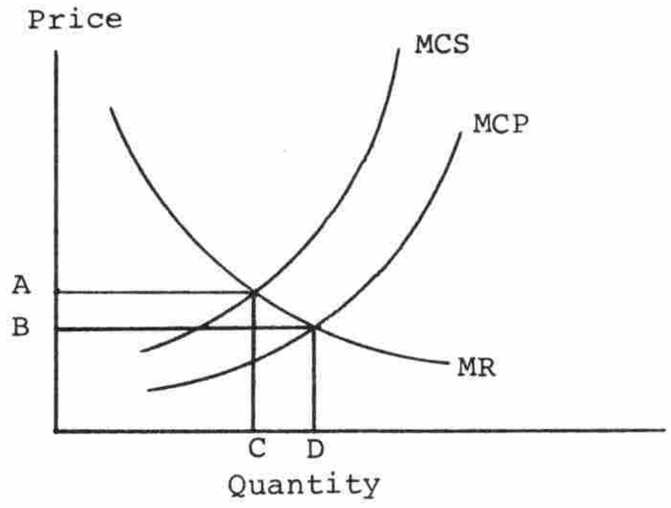
[1]There is evidence that this has occurred in Iowa (22). In 1957, the state legally assumed control of its water resources with the new water law. Although the state appears to have the right to charge regulated water users for withdrawals, policymakers have been unwilling to do so until now.

water use. First, the land market is often poorly defined due to a paucity of transactions. There will be even fewer transactions where water availability is at issue; this may obscure the demand for such land. The second reason is that water supply sources, capitalized into land prices, become a fixed cost. Except in regard to extraction costs, water use will not represent a short run production cost. The price system cannot function effectively as an allocative device in the absence of short run costs. The author has not seen any studies relating land values to water availability in Iowa.

Another type of misallocation occurs because the marginal social cost of water use is typically greater than the marginal cost to the individual. The solution which optimizes water use for the individual may differ from the solution which optimizes social welfare. This situation is known as an "ownership" externality (10); its cause is the elusive nature of the costs to society. The ownership externality is responsible for such problems as aquifer depletion due to withdrawals for low value uses of water, and municipal water supply problems caused by adjacent irrigators. The situation is depicted in Figure 3.

In Figure 3, both marginal cost curves represent the cost of water use, including extraction costs, at the margin.



MCS - marginal cost to society
MCP - marginal cost to the individual
MR - marginal revenue

Figure 3. Marginal social cost and marginal private cost

The MCS curve is drawn steeper than the MCP curve because of the increasing costs to society as water becomes a scarce good. A single marginal revenue, or marginal benefits curve was drawn; this assumes that all the benefits from water withdrawals will accrue to private individuals.[1]

If the marginal cost of water use to society could be easily calculated, simple water use fees could be used for optimum water allocation. Since the equilibrium point of water use occurs at the point where MR private = MC private,

[1]Note that this analysis is not applicable to government investments in multiple use water projects because private benefits will usually differ from public benefits.

extraction costs and private benefits will cause water use to stabilize at point D, with extraction costs at point B. This is an overuse of water, since the point where MC society = MR society represents the optimum allocation of water for society. A water use fee of AB dollars would move water use from D to C and would optimize water allocation. As stated earlier, the underlying problem is that the costs to society are difficult to define and practically impossible to quantify. Later in this study, a procedure will be demonstrated for deriving the marginal revenue curve of water in one use. Though the theory cannot be adapted to the actual situation intact, different aspects of it can be pieced together for policy decision-making.

C. Measuring the Benefits of Water Use

This section contains a brief discussion on measuring the benefits of water use in general, followed by the reasons for singling out irrigation in this study. The section is concluded with an outline of the methodology to be used for the basic model of this study, constructing a marginal value product curve for irrigation water use in Northwest Iowa.

The benefits of water use may be monetary and non-monetary in nature. Placing a dollar value on the value of water in household uses is hazardous at best, and probably not required for analyses relevant to water use in Iowa. Suffice it to say that the value of water in domestic and municipal uses, up to a certain quantity, is much higher than any other use. Above a certain point, demand may taper off quickly, suggesting a much lower value.

The hypothetical demand curve represented in Figure 4[1] shows utility gained from different levels of domestic water

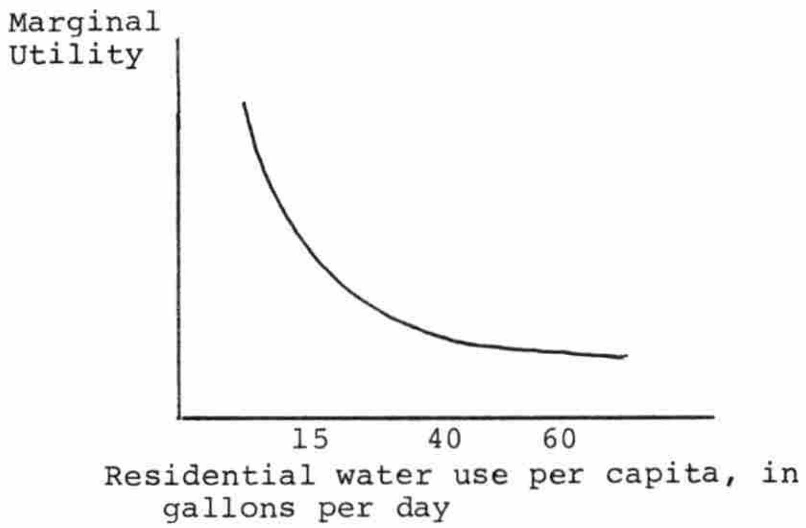


Figure 4. Utility from residential water use

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[1]Hypothetical curve based on data from Iowa Water Resources Framework Study (23).

use. Fifteen gallons per day provides a point of reference because this was the daily water allocation specified by the City of Ames during the drought in 1977. Forty gpd is indicated because this represents the mean domestic water use per person per day in Iowa (23). Some empirical demand curves may be derived from municipal data but below a certain number of gallons it will be impossible to assign a value to the water.

It is easier to assign a value to water in industrial and materials processing uses. Approximate values of water in different industrial and commercial enterprises are given in Barnard and Dent (2). More detailed studies of derived demand in such uses pose no theoretical problems though derivation of accurate coefficients may be extremely difficult.

The water use which will be emphasized in this thesis is irrigation. There are several reasons for this concentration:

1) The increase in irrigation accounts for the largest proportion of the projected increase of water use in Iowa. The increase in the number of applications associated with the drought of the mid 1970's has brought the issue of water policy in Iowa to the forefront of the decisions confronting policy makers.

2) By all reasonable estimations, irrigation is the lowest value sizeable use of water in Iowa. If an intersectoral average revenue curve were estimated for Iowa, it would probably take the form shown in Figure 5.[1] Because of the relatively low value of water for irrigation, this is the only water use likely to be substantially affected by user fees and other economically related water policy decisions.

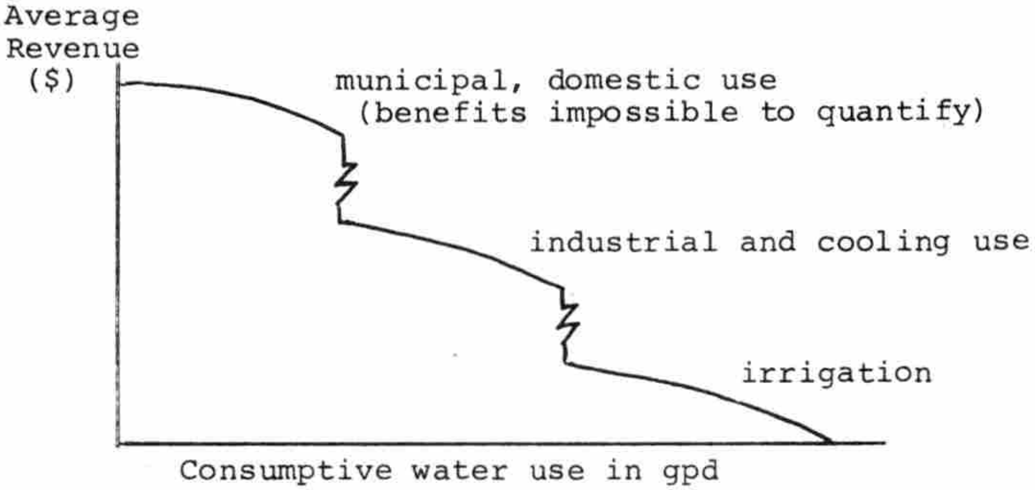

Figure 5. Average revenue from different water uses

[1]Hypothetical curve form based on data from Arizona. See, for example, Tijoriwala, Martin and Bower (48).

3) Irrigation is a consumptive use of water which facilitates the analysis.

In discussing the benefits of irrigation, private costs and benefits are combined to form marginal and average revenue curves as more acres are irrigated. Among the costs deducted from revenues due to yield increases are the fixed costs of interest and depreciation or amortization on the rig, the well, the pump, and the power source; and the variable costs of fuel and labor. The benefit that is considered is the value of the average yield increase due to irrigation. A secondary benefit that is sometimes mentioned in the literature is a decrease in the variability of yields, and therefore, income. Income variability is certainly a cost to any farmer required to make large annual expenditures; the simplest way to deal with this benefit would be to add the cost of crop insurance providing a similar degree of protection against yield variability, to the benefits of irrigation.

Among the costs listed, the only per acre cost which would vary substantially as more acres are irrigated in Iowa is the variable cost of fuel. Fuel costs would increase as the pumping depth required to sustain a yield suitable for operating an irrigation rig increased. This relationship is shown in Figure 6.[1]

In deriving a marginal revenue curve, one must look at the changes in revenue as more acres are irrigated in Iowa. The first factor to study is the average yield increase due to irrigation. Yield responses vary for different soil types and different climatic regions. The most crucial soil variable affecting response to irrigation is texture:

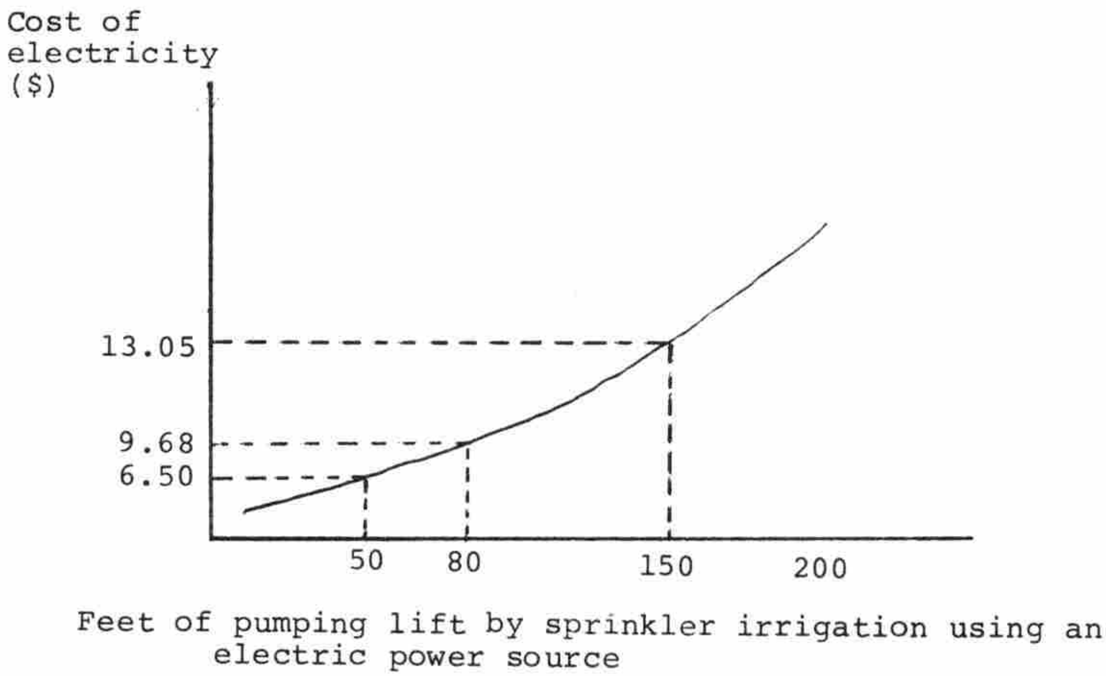

Figure 6. Cost required to apply one acre-foot of water by sprinkler irrigation using an electric power source

[1]Adapted from Sloggett (36).

lighter soils are more affected by drought than heavy soils. An appropriate variable for measuring this difference would be the available water holding capacity of the first five feet of soil. The available water holding capacity excludes gravity drained water. The parameter is expressed as a percent of total volume. It is available for all soils recently surveyed. Another possible parameter, slightly less suitable, would be the corn suitability rating. For well-drained soils within a certain region, and given a certain level of management, the main factor influencing corn yields is droughtiness. With appropriate agronomic research, a curve could be constructed on the basis of "average" weather conditions for a region of Iowa receiving a given amount of rainfall, using either of these two variables. A hypothetical form this relationship might take is shown in Figure 7.

Since the curve in Figure 7 and the one in Figure 6 represent different acreage being brought into irrigation, combining the curves into a single net revenue curve is a difficult process.

Net revenue per acre is calculated as follows:

$$AR = TR/\text{acres irrigated} = P\ \text{crop} \cdot \text{Yield Inc}$$

$$- \underset{\text{e.g. pump, well, rig}}{(FC} + \underset{\text{fuel, labor}}{VC)}$$

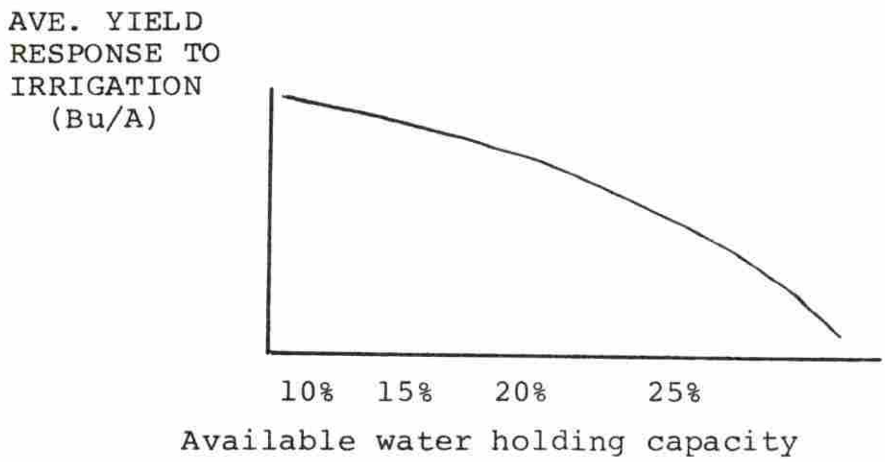

Figure 7. A hypothetical relationship between yield increases due to irrigation and available water holding capacity (given "average" weather conditions (especially temperature) and 26 to 28" of annual precipitation and top level management)

Where

AR = average increase in revenue per acre for one farm-year due irrigation

TR = total increase in revenue for all farms per year due to irrigation

P crop = per bushel price of the crop being irrigated

Yield Inc = average yield increase in bushels per acre due to irrigation

FC = annual fixed costs per acre

VC = annual variable costs per acre

MR = marginal revenue = $\frac{\partial TR}{\partial \text{acres irrigated}}$

The simplest way to calculate the AR and MR curves would be to calculate the AR at different sites likely to be irrigated (such as the sites for which an application has been received by the INRC for permission to irrigate). On the basis of the two curves mentioned before, the AR could be calculated for each of these sites. Ordering the sites according to a range of average revenues would yield the curve shown in Figure 8.

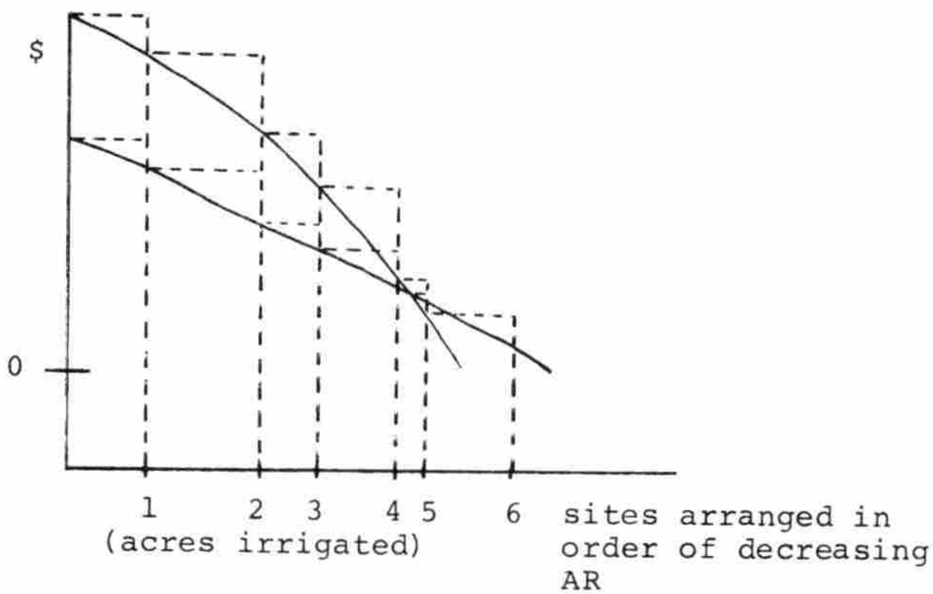

Figure 8. Marginal and average net revenue from irrigation for various soil classes (hypothetical curve)

Each of the sites would be associated with a certain number of acres, leading to the differential spacing of the sites according to the acreage it contains.

This is the approach which is used for deriving the marginal value product curve. There are few problems associated with estimating irrigation costs or predicting which land is likely to be brought into irrigation. The former has received considerable attention in the literature, especially in Nebraska (31,32,34). The latter can be predicted by examining the locations where applications for permits have already been received. Both of these problems will be addressed later in the study, but attention is now directed at the most difficult problem: estimating yield increases.

D. Estimating the Yield Increases from Irrigation

Irrigation studies in Iowa and other areas have been almost exclusively based on the results of field experiments at various research farms for a limited period of time. A summary of experiment station results for the North Central states up to 1970 can be found in Beer and Wiersma (3). Results from experimental farms provide an excellent check or a starting point for estimating irrigated corn yields. It must, however, be realized that these results are specific for a particular soil type, the climate in a single location, and usually only a few years of trials. Irrigated yields show great variability depending upon soil type and climate. There are vast areas of land, not located near any experiment station, where farmers are considering irrigation.

Perhaps most importantly, predictions of yield increases should be based on many years of weather data. This becomes particularly pertinent in view of the cyclical weather patterns in the midwest as described by Thompson (43,47).

Few authors have attempted to estimate yield increases from irrigation in Iowa. Hallberg et al. (12) listed development of an efficient method to predict yield increases from irrigation among the most pressing research needs regarding irrigation in Iowa. One study that attempts to estimate corn yield increases from irrigation is described in an unpublished letter from Dr. R. H. Shaw to Alan Charlson at the Cooperative Extension Service in Sioux City. Shaw took an approach based on his article "A Weighted Moisture Stress Index for Corn" (28). In this article Shaw demonstrates a linear relation between yield and accumulated weighted stress. Stress is defined by Shaw as $1 - \frac{ET}{PET}$ where ET is actual evapotranspiration and PET is potential evapotranspiration. Potential evapotransporation is determined by climatic conditions and is equivalent to pan evaporation. Actual evapotranspiration is calculated by a formula involving climatic conditions, soil moisture, and the state of development of the crop. The calculated stress index is weighted according to the state of crop development. The weights correspond to the yield decrement which will be caused by moisture stress for a certain number of days after planting. The relationship between stress and yield decrement is shown in Figure 9, reproduced from Shaw (28, p. 8).

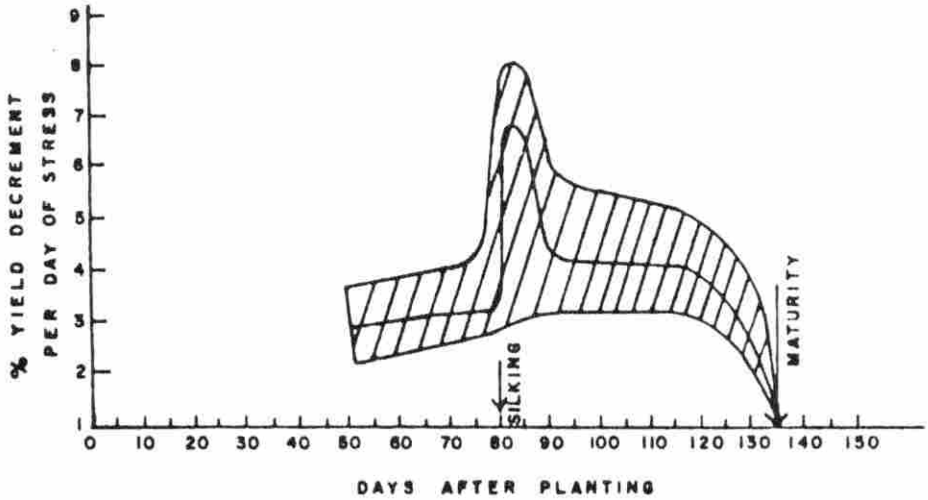

Figure 9. Schematic diagram of relationship between age of crop and percentage yield decrement due to one day of moisture stress (28)

Using this method, stress may be calculated on a daily or weekly basis, weighted according to the stage of the crop, and totaled for the season. All of the relevant parameters have been recorded at seven experiment stations in Northwest Iowa starting in the mid 1950s. In the letter previously referred to, Shaw calculated the accumulated weighted stress at the experimental station at Castana for the years 1954 to 1973. The soil at the experiment station is described as an Ida silt loam, a fairly typical soil for Western Iowa (38). The regression equation appropriate to the area (calculated by the least squares methods, based on empirical results) was used to determine the yield decrease due to the accumulated moisture stress.

Shaw then considered three levels to which the irrigator could reduce stress. These three levels were 0 units, 5 units, and 10 units, chosen arbitrarily. Reducing stress to 0 units would mean maintaining ideal soil moisture conditions for the plants at all times. This is not a reasonable assumption for any irrigator, no matter how careful. Shaw felt that 10 units of stress was a reasonable figure for the average irrigator faced with the problems of estimating soil moisture, moving rigs and following a fairly regular schedule. Using a base figure of 145 bu/acre for no-stress conditions (optimum yield), Shaw calculated that an irrigator would realize an average yield increase of 17.5 bu/acre over the 20 year period. It is important to remember that these results are specific for a single soil and location. This method can, however, be adapted and used to predict yield increases on other soils in northwest Iowa and elsewhere. Later in this chapter it is compared with other results. The method is based on empirical results and appears to be theoretically sound. Its application to irrigation problems has not yet been fully tested. Shaw's method is oriented toward conditions of moisture deficiency. He suggests a correction factor when there is excessive soil moisture but it appears to be a fairly rudimentary way of treating that problem (29).

The second method of predicting irrigation yield increases is adapted from a model developed by Thompson (44, 45,46). Thompson sought to separate out the effects of weather and technology on historical crop yields. In his model, corn, soybeans, or wheat yields were regressed on certain climatic variables such as average monthly precipitation and temperature. A time trend was also included in the regression. The purpose of the time trend was to absorb all the technological factors which were raising yields over the years. These technological factors include the adoption of improved varieties, increased fertilizer use, better machinery, and the increased use of pesticides, etc. The form of the time trend was predetermined: in a typical regression the time trend might be linear until 1960 and then quadratic after that point. Slope and intercept coefficients were, of course, generated by the least squares algorithm. Further study of the components of the time trend might possibly improve estimates of the contribution of technology to the increasing yields. For the purposes of this study, this conglomerate parameter, which encompasses all technological effects, appears to be sufficient.

Thompson improved his results as he increased the area of study. Multiple correlation coefficients (R^2) increased from approximately 90 percent for a single crop reporting district to close to 95 percent for a multi-state area. In direct contrast with Shaw's model, which is geared to a single site, Thompson's model performs best for very large areas.

When Thompson held all other variables constant and plotted one climatic variable (such as July temperature) against yield, the curve took on the form of a concave parabola (44,45,46). The general shape of this curve is shown in Figure 10.

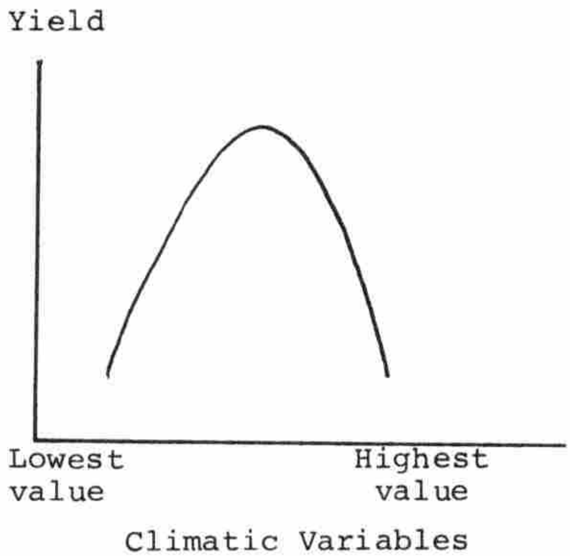

Figure 10. The general relationship between yield and several relevant climatic variables

This shape occurred for all the climatic variables in the model. The coefficients of the curve were determined by the least squares algorithm. When the model was applied to pooled data of five Corn Belt states, all variables were significant at the 99 percent level.

Although Thompson developed this model for separating out the effects of weather and technology, it can be used for many other purposes, such as calculating yield increases from irrigation. The procedure for doing this consists of the following steps:

1) Adapt the model to the region to be studied.

2) Separate out the effects of weather and technology as provided for in the model.

3) Create a new yield variable which will reflect the effects of weather for each year, but which will hold technology constant at the level of a single year.

4) Maximize the yield with respect to all variables under the control of the irrigator. These variables are pre-planting soil moisture, June precipitation, July precipitation, and August precipitation. These variables are assumed to be under the control of the irrigator because the effect of irrigation is assumed to be identical to precipitation.

5) Subtract the variable created in (3) from the optimized variable created in (4) to determine the average yield increase for each year from irrigation.

This is the procedure which was used in this study. The resulting yield increases generally correspond with experimental data, but they are deficient because they apply to an average of all the soils in the area being studied. The soils which are actually being irrigated tend to have a higher yield response than the average. The crop which was studied is corn, and theregion is the twelve county crop reporting district of Northwest Iowa. The five steps outlined above will now be examined in detail.

1. Adapting the model to the region:

After running numerous regressions for the northwest Iowa data, the variables shown in Table 1 were finally chosen as those which best explained the variation in corn yields.

The temperatures are given in degrees Fahrenheit, the precipitation in inches, and the yields in bushels per acre. The multiple correlation coefficient derived from regressing corn yields from 1928 to 1976 on these 13 variables is 92.2%. There are 35 degrees of freedom associated with the residual. The F-value is significant at the 99.9% level. A graph of the predicted versus actual yields is given in Figure 11.

As seen from Table 1, five variables are significant at the 99% level, and four at the 90% level. Of the remaining four variables, three were included

Table 1. Regression variables used in the model

Parameter	Parameter name	T-value	Significance level
Intercept	Intercept	-2.56	99%
Linear time trend	NO	4.88	99%
July precipitation	P7	3.06	99%
August precipitation	P8	3.09	99%
Square of August precipitation	SP8	-2.83	99%
June temperature	T6	1.82	90%
Square of June temperature	ST6	-1.82	90%
Precipitation for January to June	P1_6	1.08	70%
Square of precipitation from January to June	SP1_6	-1.08	70%
July temperature	T7	2.31	95%
Square of July temperature	ST7	-2.40	95%
First quadratic time trend	TSQ1	3.47	99%
Second quadratic time trend	TSQ2	-.50	Not significant
Square of the precipitation of the previous fall	SPLAG	1.35	80%

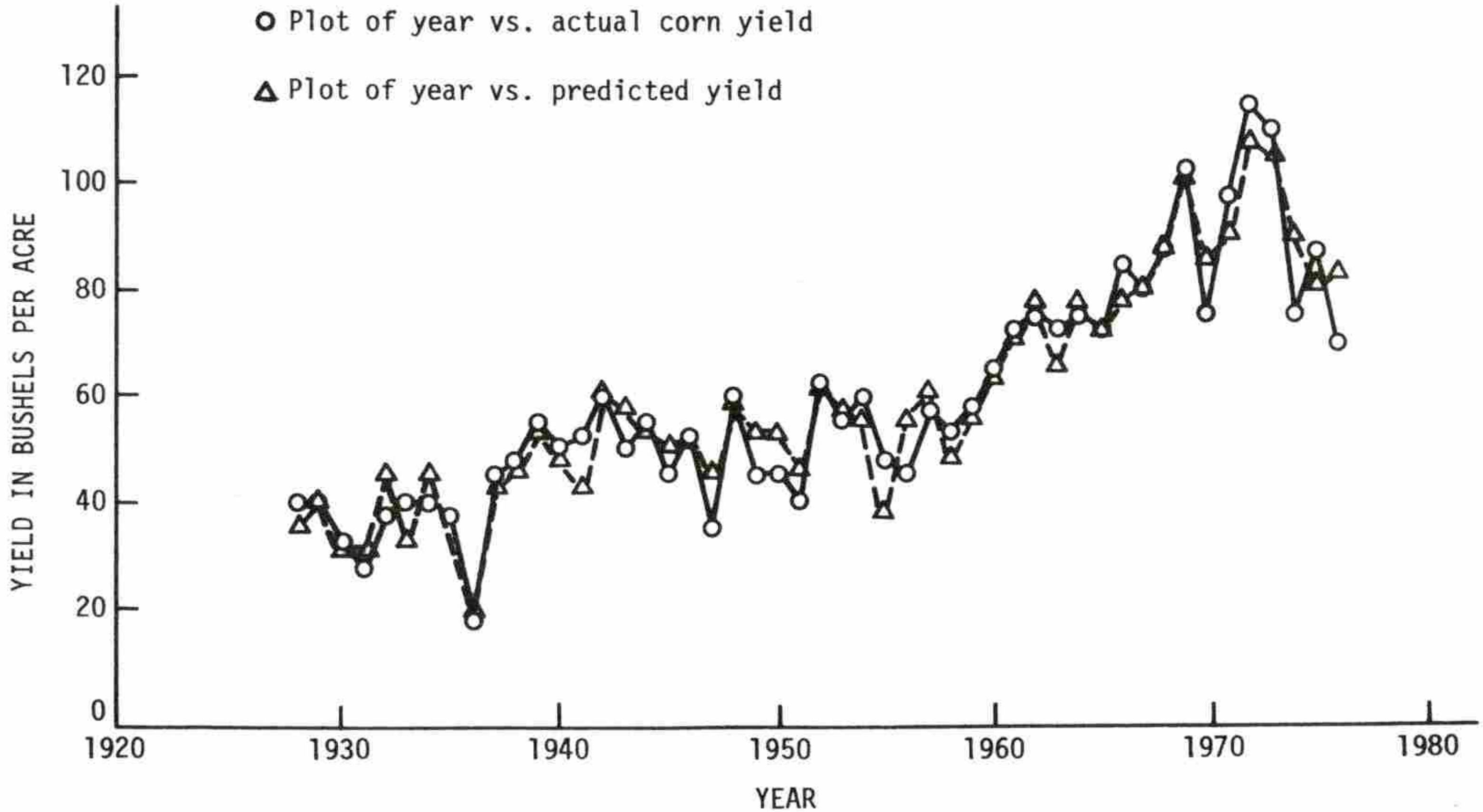

Figure 11. Predicted versus actual yields

(P 1_6, SP1_6, SPLAG) because they were reasonable choices on the basis of "a priori" information on agricultural climatology, and because of their consistent estimates in the numerous variations of the model which were run. The other variable is the second quadratic time trend variable.

2. The time trend took the form shown in Figure 12:

The time trend was confined to a linear shape for the years 1928 to 1957. During these years, the adoption of new technology proceeded at a fairly gradual rate. From 1958 to 1969 the time trend was allowed to take a quadratic shape. The quadratic is convex indicating an increasing level of technology at an increasing rate. This closely approximates the trend of fertilizer use for that time period (44). A second quadratic parameter was included in order to permit the rate of increase in technology to level off in the years 1970 to 1976. All slope and intercept coefficients were determined by the least squares algorithm. The second quadratic parameter forced the technology trend to slope downward after 1973. Since the hypothesis of a decreasing level of technology is untenable, it must be concluded that either the technology parameter was absorbing some of the effects of the poor weather of the 1970's or that the technology parameter had absorbed some of the effects of the good weather of the late 1960's. (Another possible explanation for this result is the termination of

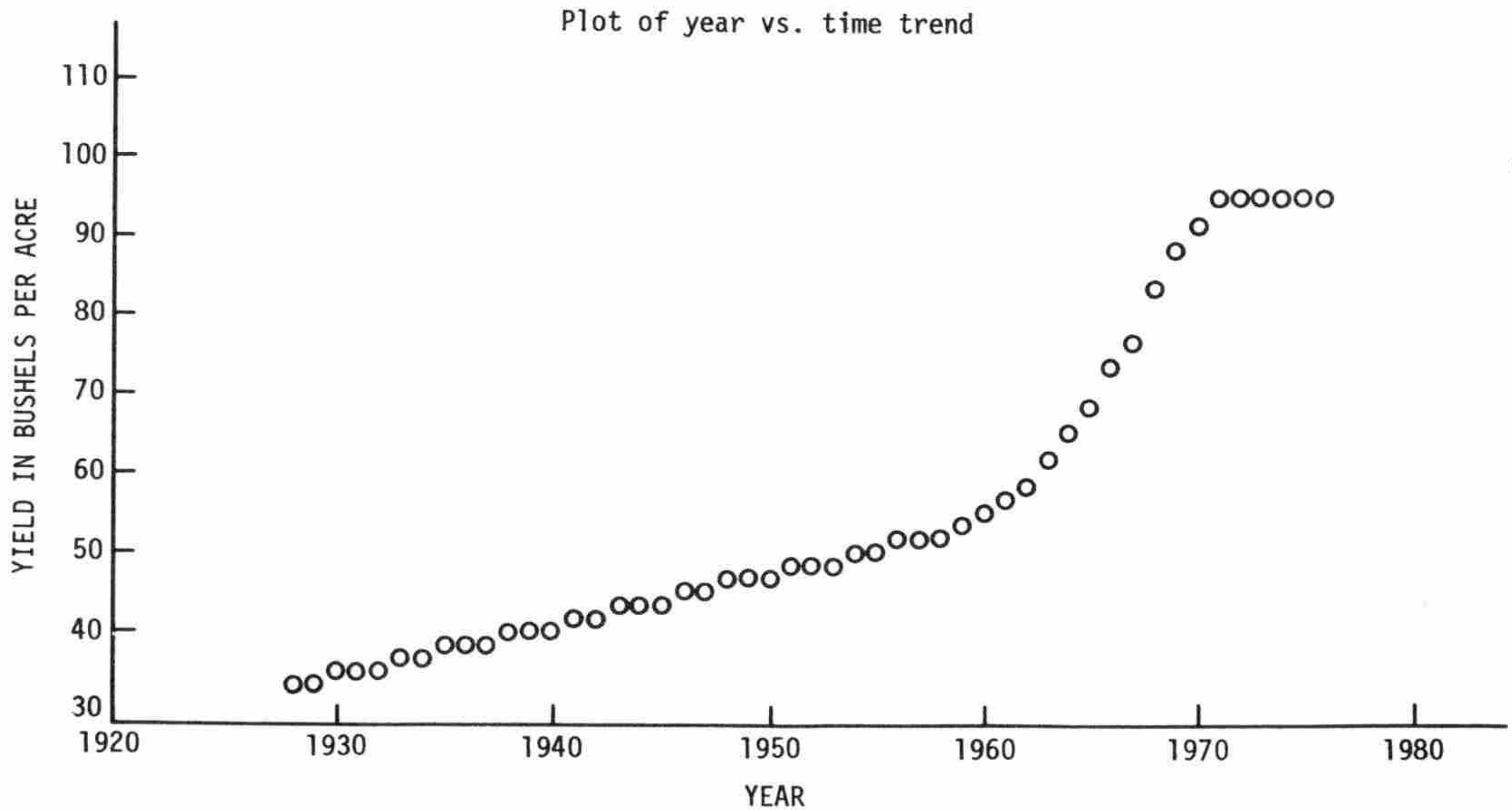

Figure 12. Plot of year vs. time trend

the set-aside programs in 1973 which brought considerable portions of poorer quality land into production). To correct for this problem, the time trend was forced to assume a constant level after it reached its maximum in 1971. This is the reason that the second quadratic time trend variable has an insignificant T-value. All the time trend variables are grafted polynomials with continuous first derivatives. A comprehensive study of the rate of adoption of several important technologies should resolve problems regarding the shape of the time trend.

3. The variable which was created to reflect the effects of weather on corn yields at a constant level of technology is called CY76. It is based on 1976 technology and has a maximum value of 107.9 bu/acre (in 1969) and a minimum value of 70.7 bu/acre (in 1936). Its mean value is 94.4 bu/acre.

4. In order to approximate the yields which an irrigator could attain in each of the years modeled it was assumed that certain parameters are under the control of the irrigator. These variables are as follows:

Pre-planting precipitation (January through June precipitation)	(P 1-6)
July precipitation	(P 7)
August precipitation	(P 8)

The effect of sprinkler irrigation on the crop is sufficiently similar to that of precipitation to make this assumption valid. By holding all other parameters constant at their means and allowing only one of the parameters (P 1-6, P 7, or P 8) to vary, the curves showing the relative effect of each of these variables on yield can be drawn. These curves are given in Figures 13a 13b and 13c.

a. The graph of July precipitation vs. yield is linear. It is known from crop physiology that eventually yield will decrease as more water is applied. Apparently this point has not been reached in the years being modeled in Northwest Iowa. The graph of July precipitation vs. yield does assume the characteristic parabolic shape in Thompson's model of five Corn Belt states. Though the optimum level of July precipitation is not reached in this model, a "proxy" optimum was selected on the basis of three criteria:

1. the optimum July precipitation when the parameter was forced to assume a parabolic shape;
2. the optimum July precipitation used by Thompson (44); and
3. Shaw's estimate of the optimum July precipitation.[1]

[1]Dr. Shaw, Professor of Agronomy, Iowa State University, Ames, Iowa, personal communication, 1978.

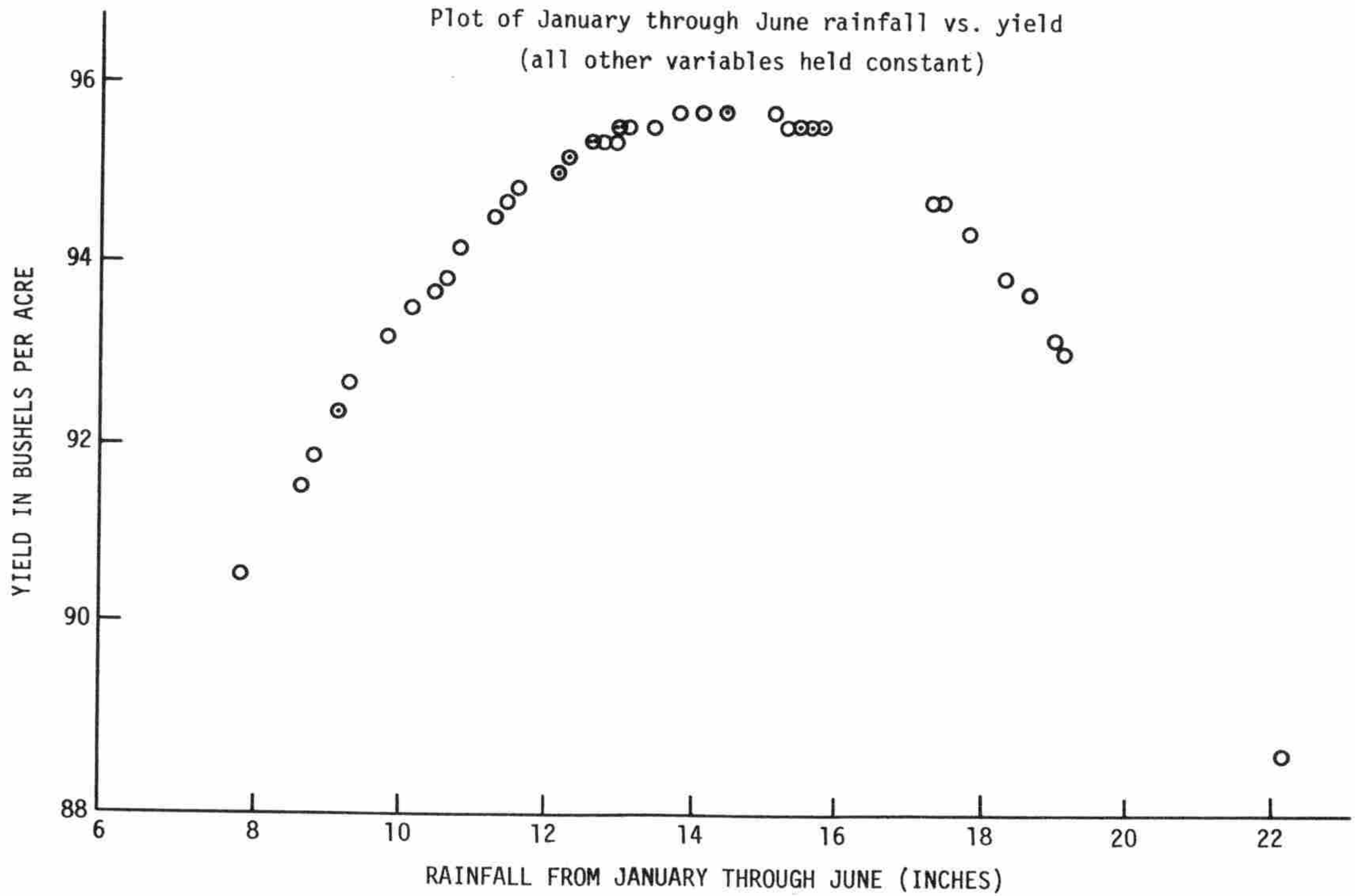

Figure 13a. Plot of January through June rainfall vs. yield (all other variables held constant)

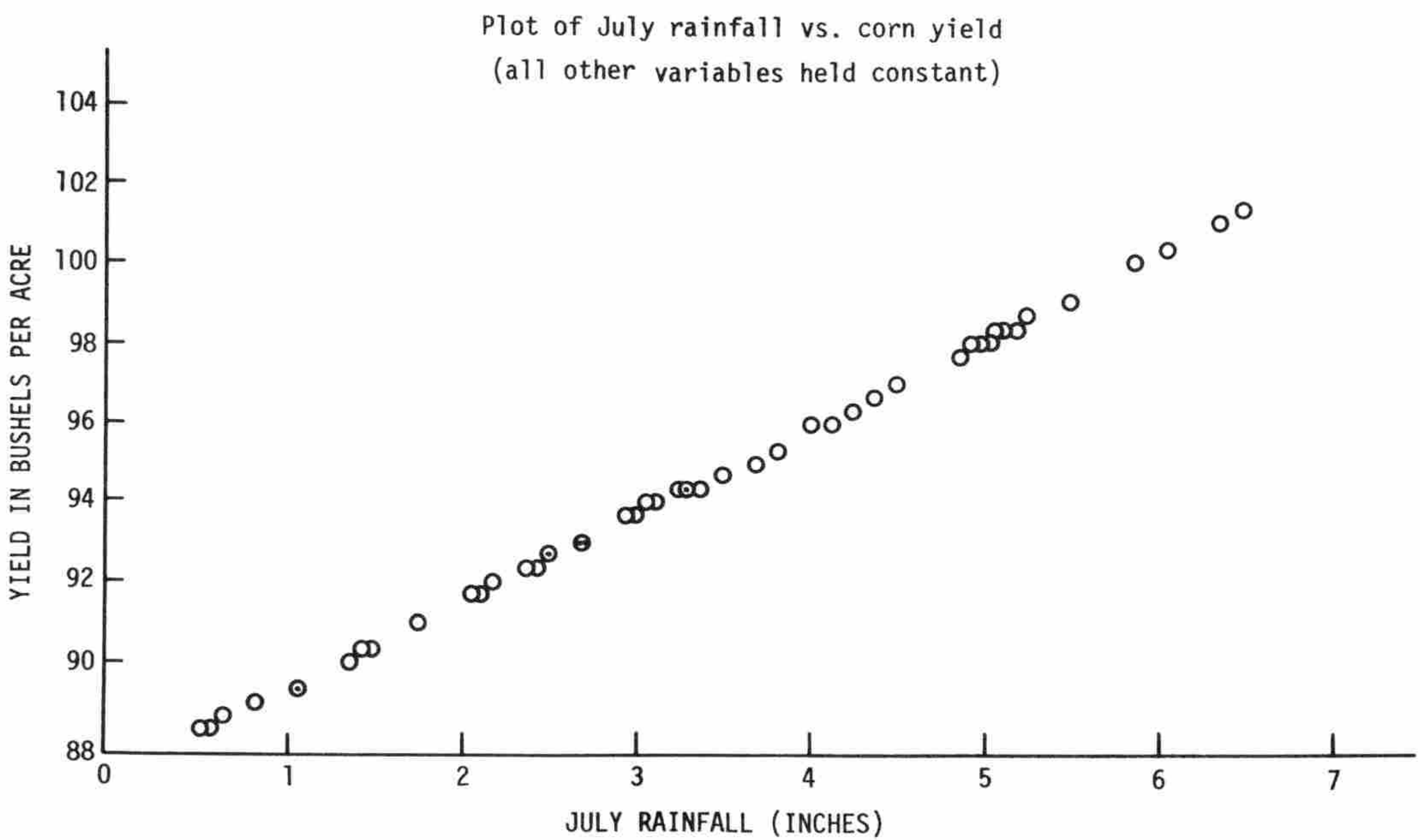

Figure 13b. Plot of July rainfall vs. corn yield (all other variables held constant)

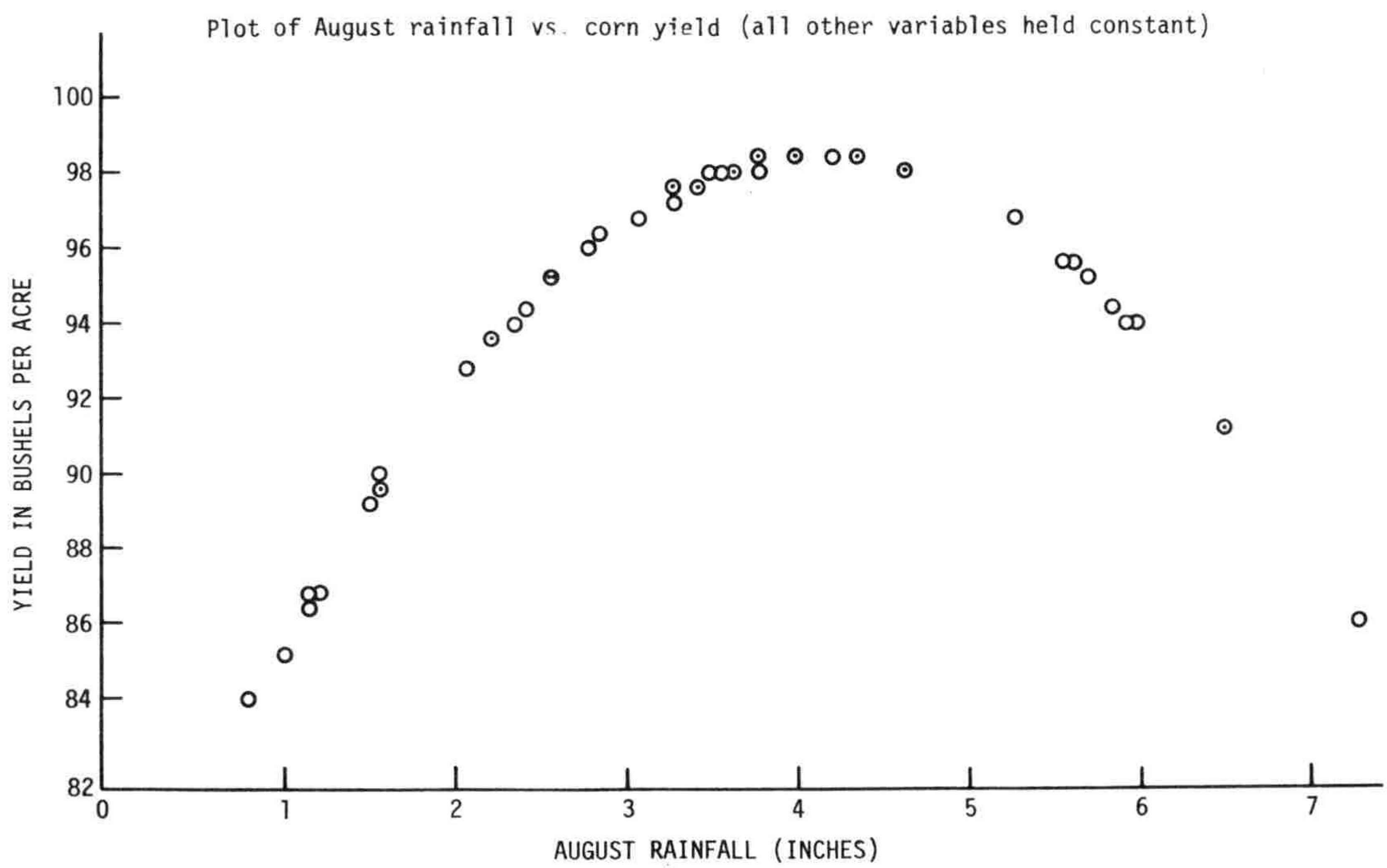

Figure 13c. Plot of August rainfall vs. corn yield (all other variables held constant)

The figure which was selected as the optimum was 7.58 inches of precipitation in July.

b,c. August precipitation and January through June precipitation do assume a parabolic shape when plotted against yield. The optimum value is clearly defined on the graph. It is given mathematically by the point at which the first derivative of the quadratic precipitation function with respect to yield is equal to zero. These points were calculated to be 4.16 inches of precipitation in August and 14.45 inches of precipitation before planing (from January through June).

One possible problem with the procedure followed is that high ends of both of these curves were associated with lower yields and an irrigator can only increase soil moisture, not decrease it. This should have little impact on the model because most soils being irrigated are coarse textured and well-drained. Crop losses due to excess moisture would be minimal on such soils.

The variable which was created to show the maximum attainable yields by irrigators for the years 1928 to 1976, based on 1976 technology, was called OPY76. It was calculated by replacing the actual precipitation with the optimum precipitation and keeping the 1976 level of technology. Figure 14 shows the variables CY76 (corn yields with 1976

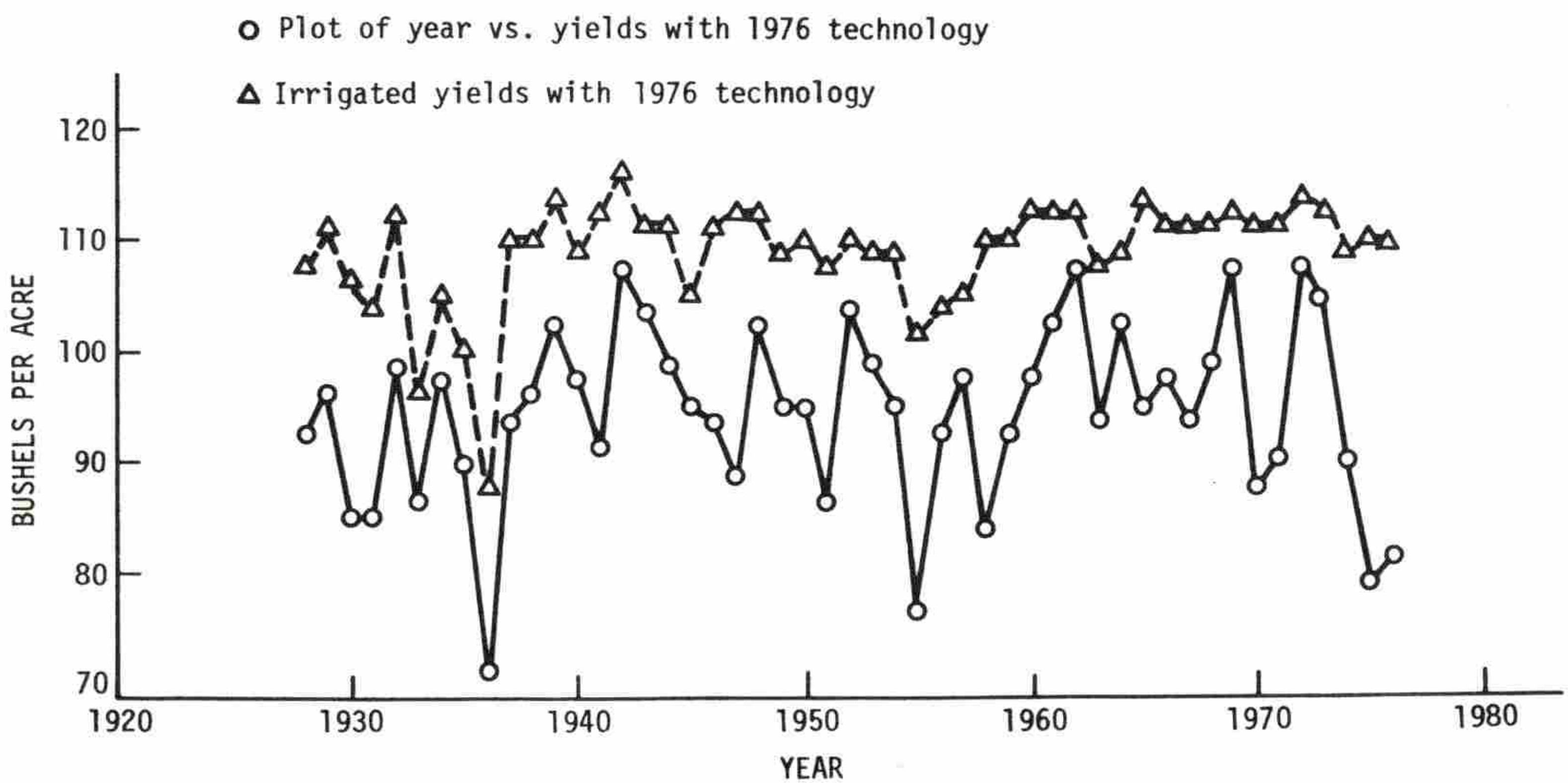

Figure 14. Irrigated and nonirrigated yields with 1976 technology

technology) and OPY76 (irrigated yields with 1976 technology).

5. Yield increases from irrigation are calculated by subtracting CY76 from OPY76, or normal yields with 1976 technology from irrigated yields with 1976 technology. The maximum yield increase was 30.27 bu/acre (in 1975) and the minimum yield increase was 4.99 bu/acre (in 1962). The mean yield increase from 1928 to 1976 was 14.52 bu/acre. A variation on this model is to subtract the actual yield rather than the predicted yield from the irrigated yield. This method creates a variable (called YINC2) which appears to approximate actual results better than the basic yield increase variable (YINC1). The graph is given in Figure 15.

To check the accuracy of these results, they were compared with various experimental results. In Figure 16a, the results are compared with five years of irrigated yield data from Burt County, Nebraska (12).[1] In Figure 16b the results are compared with yields at the experimental station in Ames, Iowa (4).

The major observation derived from these graphs is that the model follows the same general trend as the actual results. The results should not be identical; neither of the

[1] Burt County is located west of Monona County, Iowa.

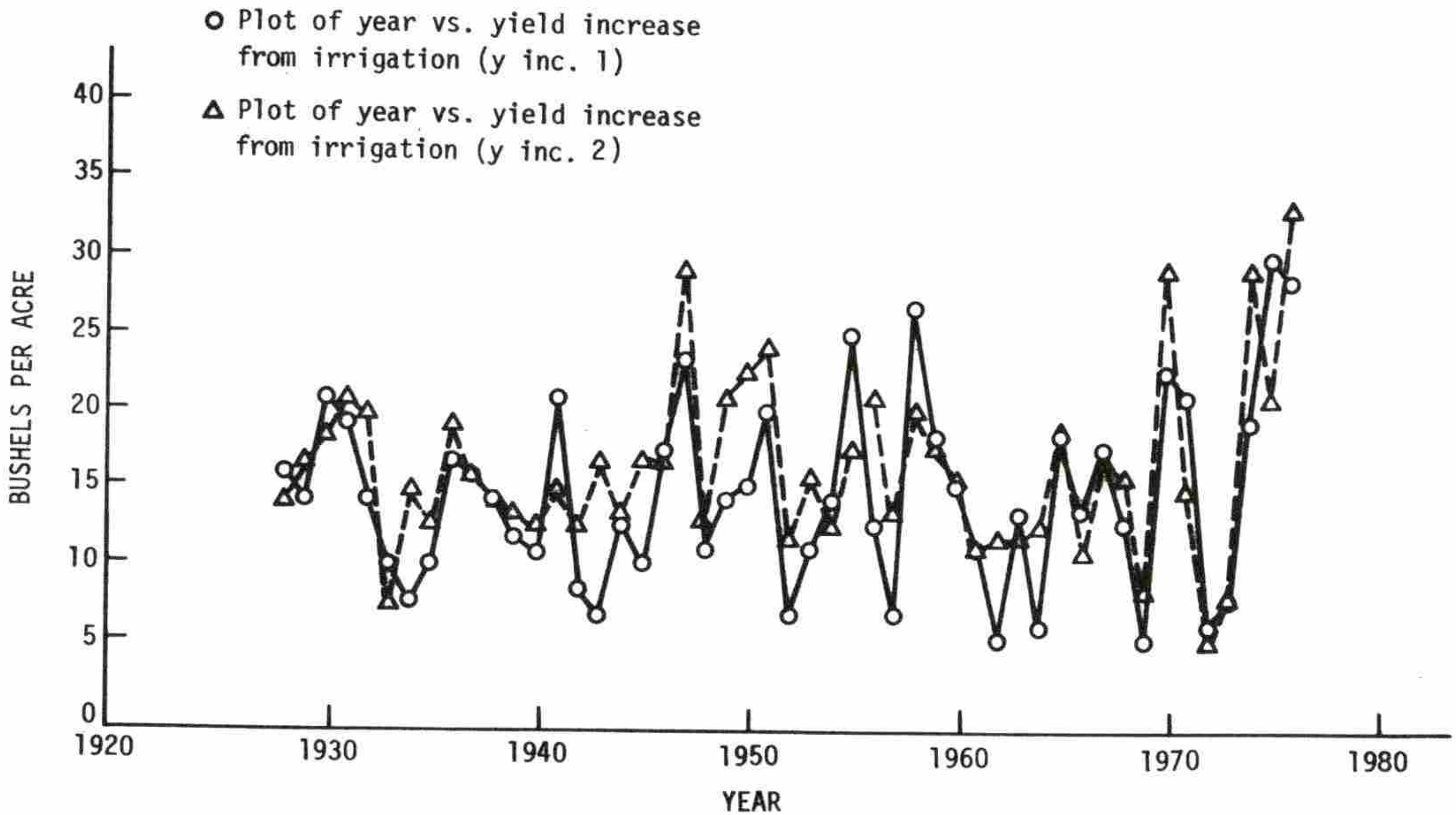

Figure 15. Year vs. yield increase from irrigation calculated using two methods

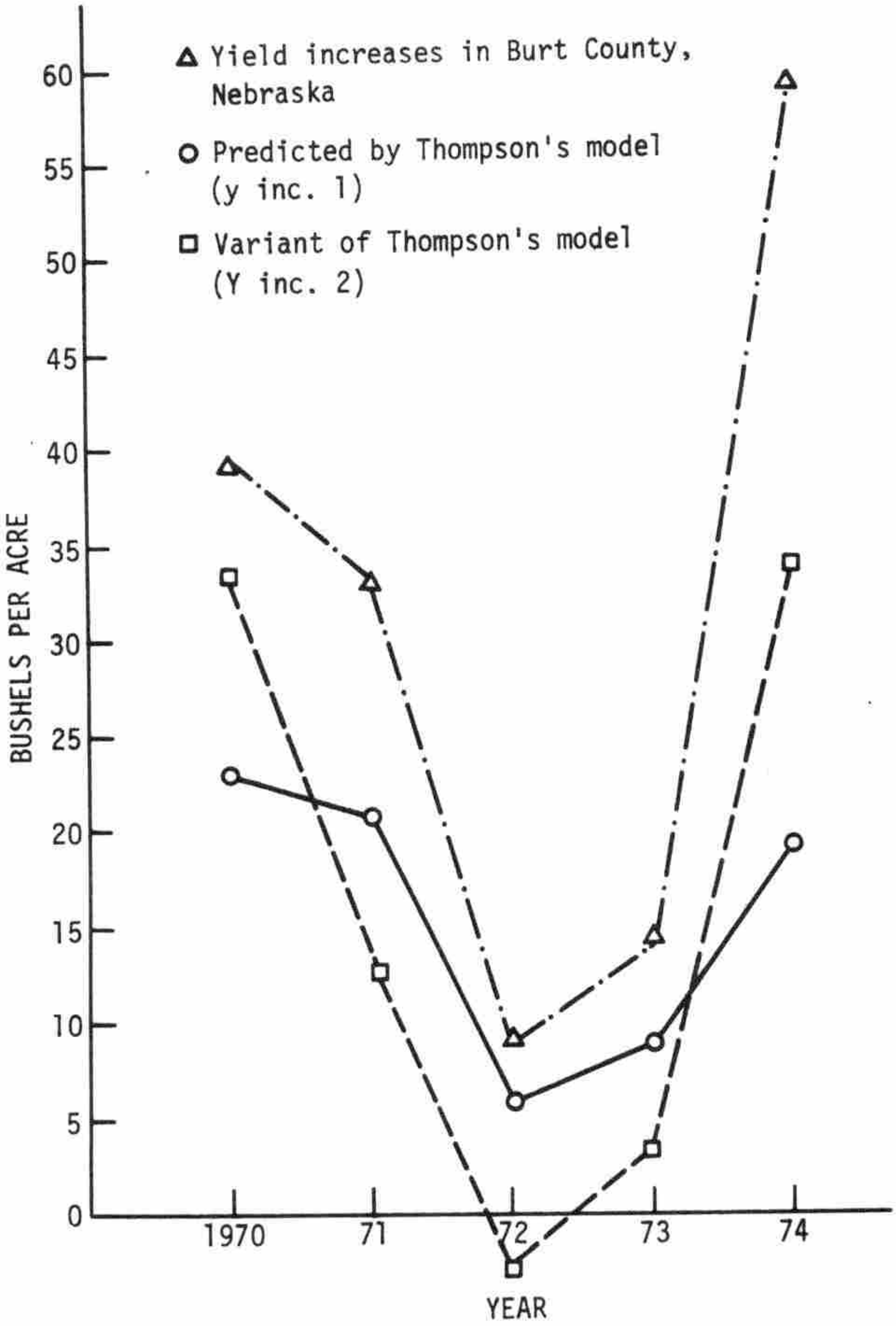

Figure 16a. Predicted and actual yield increases (Nebraska) from irrigation

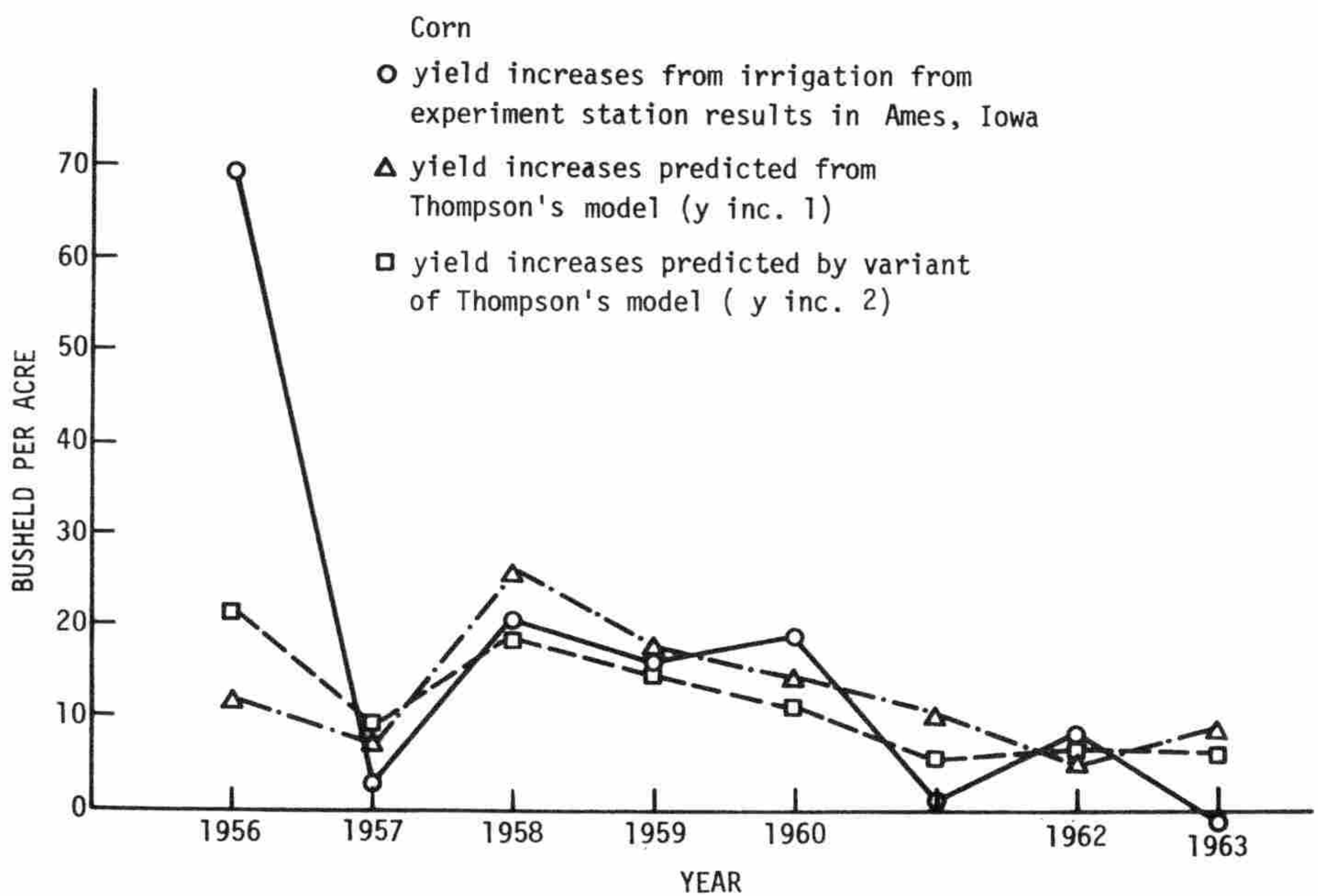

Figure 16b. Predicted and actual yield increases (Ames) from irrigation

experimental results is located in Northwest Iowa, and the soils being observed are different. One observation that appears to be significant is that the very large yield increases that occurred in several years are considerably muted in the model predictions. This can be observed in the Nebraska data in 1970 and 1974 and in the Ames data in 1956 (Figures 16a and 16b). This fact can be explained in two ways. It is probable that the Nebraska and Ames data reflect soils more responsive to irrigation than the average. The model predicts yield increases on an average of all soils in Northwest Iowa, which includes many soils relatively unresponsive to irrigation. The second explanation is that the model underestimates the degree of variation attributable to precipitation. This may be especially true in very dry years. The consistent underestimation of yield increases observed in the comparison with the Nebraska data is probably caused by a combination of these two factors. The Nebraska data gives a better check on the model than the Ames data because the Nebraska sites are closer to Northwest Iowa than the Ames site and because the Nebraska data are based on an average of irrigated soils, rather than a single soil type.

Comparisons between Thompson's Model and Shaw's Model:

In order to compare Shaw's procedure with Thompson's model, yield increases from irrigation were calculated through Shaw's procedure for Northwest Iowa. Weekly soil moisture records have been kept at five stations in Lyon, O'Brien, Buena Vista, Plymouth, and Emmett Counties since 1959. Shaw (28) calculated an accumulated stress index for each of these points. These indices were averaged together to give an average for Northwest Iowa.

The regression equation which associates yield with accumulated stress is 9119-90.3 X. Thus, if the accumulated stress is substituted for X for each of the years from 1959 to 1978, the resulting figure is the predicted yield in kilograms per hectare.[1] These yields are predicted on the assumption that if no stress had occurred, a maximum yield of 145 bushels per acre would have been attained. As explained in a previous section, Shaw's procedure does not assume that an irrigator can eliminate stress completely. Instead, a certain amount of stress is arbitrarily chosen which will occur despite irrigation. This remaining level of stress has two causes. If the weather is sufficiently hot and

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[1]The regression equation has since been revised by Shaw.

dry, a certain amount of stress will occur no matter how much irrigation water is applied. The second cause is the inability of most irrigators to commence applications at the exact moment soil moisture falls below the 60% level. This may occur because the equipment is being used on the other side of the field or on a neighboring field at that moment. Following Shaw's suggestion, 15 units of stress, corresponding to a yield decrease of 21.3 bushels per acre was chosen as this level. Following this procedure, yield increases from irrigation as calculated by Shaw's and Thompson's models are shown in Figure 17.

Some of the patterns are similar on these two graphs, but there are also large discrepancies. The results from Thompson's model accord better with the Nebraska data. Shaw's model appears to predict yield increases well over small areas, but falls short in large area averages. The average of the five soil moisture sample points had a very large variance. This tends to discredit the acceptance of the five point soil moisture average as a reliable average for the entire area.

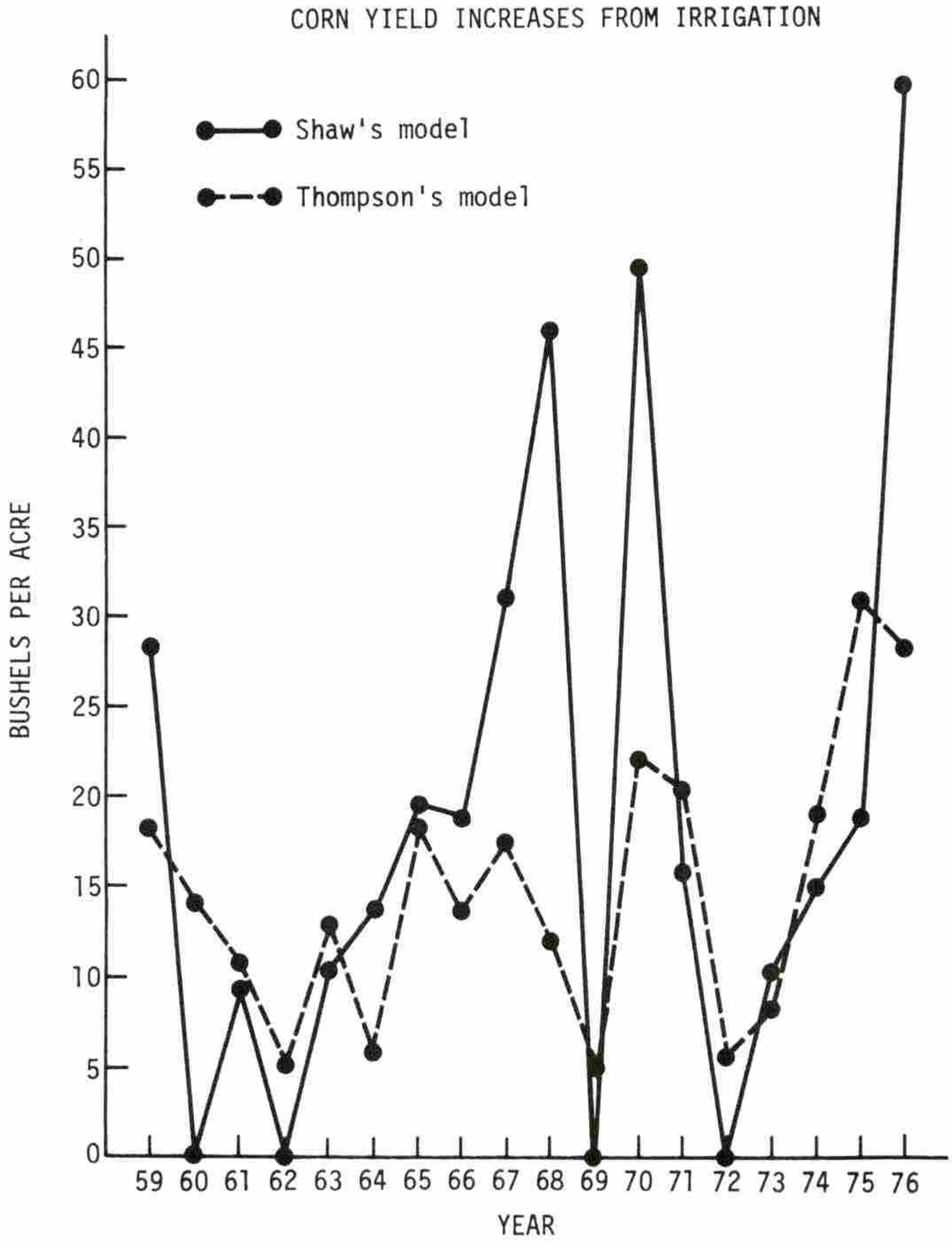

Figure 17. Corn yield increases from irrigation

Drawbacks of the Thompson Model:

There are several drawbacks associated with the Thompson model. The monthly precipitation figures do not indicate if the rainfall occurred in one large storm, which may have hurt the crop, or in evenly spaced, gentle rainfalls. This problem could be resolved either by subtracting off surface runoff, monitoring soil moisture, or by taking weekly or daily rain data. This was not done in this study because the methods involved are more complicated and this type of data is not available for a long period of time. Another variable which might have proved significant is the average planting date. Again, this parameter was not available for all the years modeled.

The most important drawback has already been referred to. The results of the model may give an accurate estimate of yield increases from irrigation for an average of all soils in the region being studied. Actual yield increases will diverge greatly from these estimates for specific soil types. In order to correct for different soil types it appears that an adjustment factor can be introduced. This adjustment factor would be based on some quantitative characteristic of the soil, such as available water capacity in the first five feet, or corn suitability rating.

Yield response data were also obtained from interviews with eight irrigators in Northwest Iowa. The data can be assumed to be accurate only for 1976 and 1977 as no written records of yields were kept by irrigators.

Several results can be gained from the interview data. Figure 18 shows yield increases in 1976 and 1977 on the eight farms. 13 sites are shown because five of the farms have two different soil types being irrigated. The sites are listed in order of increasing yield increases.

Each point represents the yield increase on a particular soil being irrigated. Differences in yield response reflect management and slight differences in the weather in addition to the soil type. In 1977, yield increases were clustered in the 40 to 80 bu/acre range while in 1976 most were clustered in the 60 to 130 bu/acre range. These are well above the "average soil" yield increases predicted in the Thompson and Shaw models. This is due to the fact that most of the soils shown are shallow and coarse textured.

The 13 soils shown on this graph correspond to the following soil types:

1. 50% Clarion Loam and 50% Marshall Silt Loam
2. 70% Lamoure Silty Clay Loam, 20% Clarion Loam, 10% Sioux Loam with a very high water table.
3. Same as 2, but without a high water table.
4. 40% Fargo Silty Clay Loam and 50% Lamoure Silty Clay Loam.
5. 40% Carrington Loam, 30% Sioux Loam, 30% Wabash Loam.

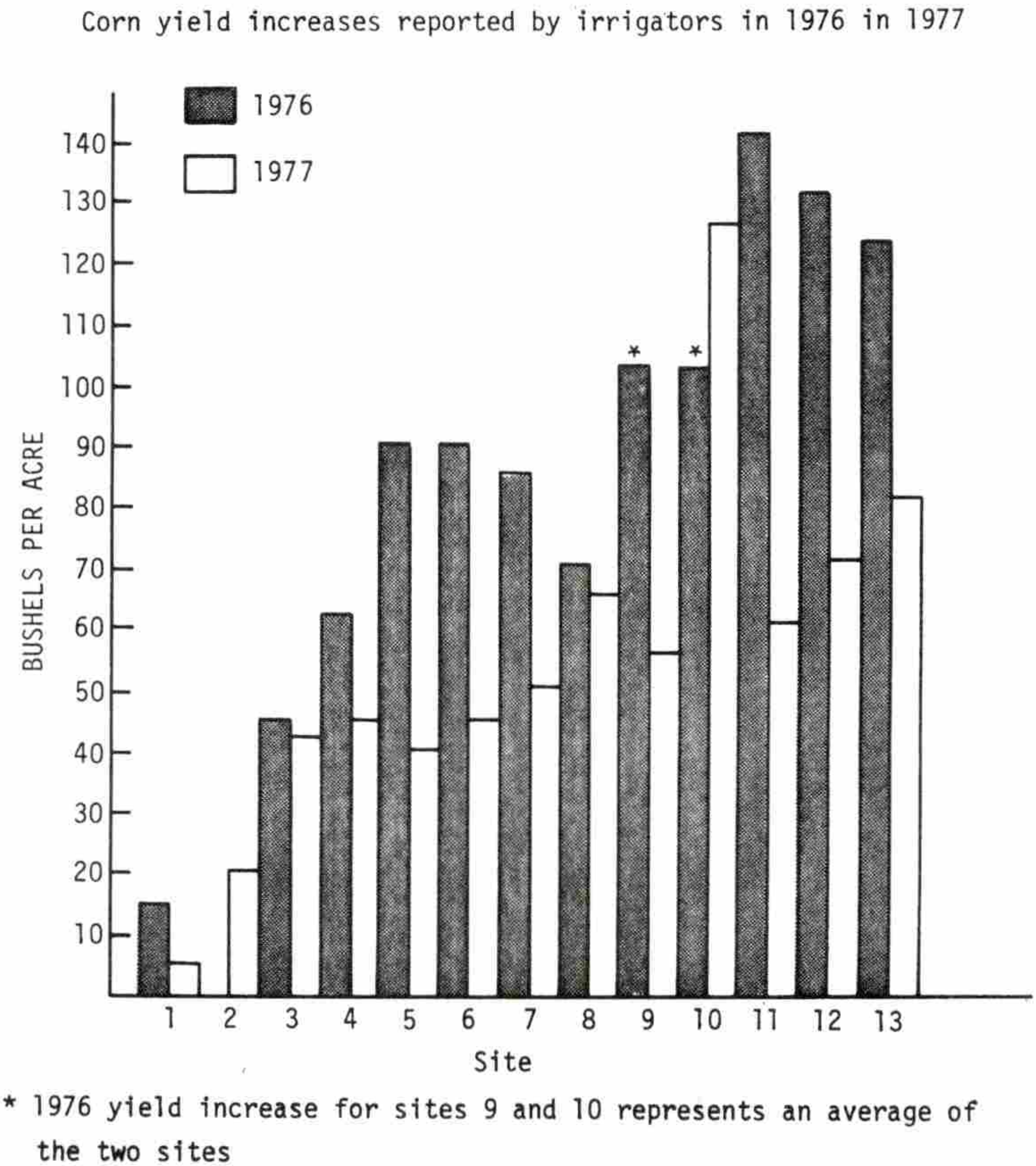

Figure 18. Corn yield increases reported by irrigators in 1976 and 1977

6. Lamoure Loam underlain by sand at 8 to 10 inches.

7. Sioux Loam.

8. Colo Silty Clay Loam.

9. Sioux Fine Sandy Loam.

10. 93% Marshall Loam, 7% Carrington Loam.

11. Sioux Loam.

12. Wabash Loam.

13. Luton Silty Clay Loam.

All the soils listed correspond to "old" soil surveys except the Colo Silty Clay Loam and the Luton Silty Clay Loam. These are on a farm in Plymouth County which was surveyed very recently. Five of the farms interviewed are located in Sioux County which was last surveyed in 1915 (41). The remaining farms are located in Lyon County, last surveyed in 1927 (38). Soils from these surveys are very general. There are usually many different modern equivalents for a single soil type shown on the old survey.

This is an unfortunate occurrence as it makes it impossible to check the interview data for correlation between most quantitative soil characteristics and yield response to irrigation. It is likely that some relation between available water holding capacity or corn suitability rating and yield response to irrigation exists but this hypothesis cannot be checked. It would require an agronomic study of various soils and their responses to irrigation to fully solve the problem of the marginal value product of water in irrigation use.

The question of expected yield increases from irrigation on "average" soils has been resolved to a large extent by the close concordance between empirical results and results derived from the Thompson and Shaw models. Using Thompson's model, the average yield increase is 14.5 bu/acre over a 49 year period. Using Shaw's model, the average yield increase is 17.5 bu/acre over a 20 year period.

For selected coarse textured soils in Iowa, the interview data shows that much higher yield increases can be expected. The exact relationship cannot be shown because good soil data is missing for most of the farms interviewed.

In the next chapter, the results obtained are applied to the water situation in Iowa. Before doing so, attention is turned to irrigation costs.

E. Costs of Irrigation

Irrigation costs have received considerable attention, particularly from farm management experts and extension agents. Sheffield (32,33,34) at the University of Nebraska has probably compiled the most data in this area. Charlson (6) gave estimates of irrigation costs in the Missouri Bottomlands in Iowa in a 1976 study. Irrigation costs in

Iowa were also estimated by Eisenhauer and Fischbach (7) in 1976. These costs are compared with cost data obtained in the interviews with eight irrigators in Northwest Iowa.

The estimates obtained in the four studies are given in Table 2. The figures are per acre costs for a center pivot system on a single quarter section of land. No land leveling or underground pipe costs are included. The costs shown are those over and above what is required for dryland farming. Since the Sheffield study (35) considered all the costs involvied in growing crops under irrigation, certain costs reflecting differences between irrigated and dryland farming were not explicitly included. These costs, in parentheses, were borrowed from the Charlson (5) figures. The Sheffield study calculated depreciation, interest, taxes, and insurance very carefully. These ownership costs come very close to 12.2% of the total investment, a figure which is used by Charlson. Sheffield assumes a 400 ft. well, Eisenhauer and Fischbach a 150 ft. well. Charlson does not specify the depth of the well, but 125 ft. would be typical of the Missouri bottomlands situation.[1] The average depth of well for the irrigators interviewed was 78 ft. Since many of the irrigators interviewed used electrically powered systems, the initial investment is an average of both diesel and electric systems. The fuel costs

[1]James Weigand, Deputy Water Commissioner of Iowa, personal communication, 1977.

Table 2. Irrigation costs for a center pivot system with a diesel engine (costs are for 135 acres being irrigated)

	Charlson (5) Estimate (dollars)	Sheffield (35) Estimate (dollars)	Interview Data[a] (dollars)		Eisenhauer & Fischbach (7) (dollars)
1. Initial investment	45,825.00	61,891.00	41,820.00		46,150.00
2. Ownership costs (per acre)					
a. Depreciation		30.11			
b. Interest	12.2% of	1.44	12.2% of		
c. Taxes	investment	23.27	investment		
d. Insurance		1.25			
TOTAL	41.23	56.07	37.30		47.61
3. Loss of land (equipment path): $85 cash rent x $\frac{1}{2}$%	.43	(.43)	(.43)		
4. Irrigation operating costs					
a. Fuel	7.43	18.17	6.24 or	9.10	15.52
			(diesel)	(elec.)	
b. Repair and maintenance	4.85	4.03	4.64	4.64	5.54
c. Labor @$4.00/hr	1.00	1.35	.97	.97	2.00
TOTAL	13.19	23.55	11.85	14.71	23.06
5. Additional crop production costs					
Additional seed	2.00	4.00	3.54	(these costs	
Additional fertilizer:				not included	
N	4.80	(4.80)	20.45	in study)	
P_2O_5	4.50	(4.50)	0		
Additional harvest and drying cost (for 31 bu/acre yield increase)	3.10	(3.10)	3.41		
TOTAL	14.40	16.40	27.40		
			diesel	elec.	
GRAND TOTAL	69.25	96.47	76.98	79.84	70.17

[a]Results of personal interviews conducted with irrigators in Northwest Iowa. A copy of the interview questionnaire is presented in Appendix C and a summary of results in Appendix B.

for diesel and electricity were kept separate. For details on how each estimate was determined, please see Appendix B.

Cost increases for upland sites:

All costs computed thus far assume sites located on a floodplain and overlying a shallow alluvial aquifer. These have been the most widely exploited sites because the extraction costs have been lowest. The average well depth among the irrigators interviewed was 78 feet. All but one were on the floodplain and even that one (farm no. 6) appeared to be tapping an alluvial aquifer. The average lift was estimated from the well logs as 30 ft. A nationwide study of irrigation pumping lists the average lift in Iowa as 35 feet (36). That figure is heavily weighted by the average lift in the Missouri Bottomlands area where the majority of the irrigation in Iowa is taking place.

A farmer in Northwest Iowa not located on the floodplain would in most cases have to withdraw water either from a buried channel or from the Dakota Sandstone aquifer in order to irrigate. Buried channels occur in many parts of the state but their location and water bearing characteristics are often unknown. They are also too variable in terms of depth and static water levels to conform to any generalizations (18). Thus, attention will only be directed towards the costs of irrigation from Dakota wells. Depth to the

Dakota Sandstone and static water levels vary according to the location in the state. The situation is further complicated by the even greater variability of pumping water levels by location.[1]

The average depth of well used in this study for Dakota Sandstone wells is 500 feet, with 250 feet of lift. This figure was used by Charlson (5) in his estimate of upland irrigation cost and its general accuracy was confirmed by Deputy Water Commissioner Wiegand.[2] Charlson's (5) estimate of costs is shown below:

1.	System	$59,125.00
	Investment per acre	437.00
2.	Irrigation ownership cost (12.2% of investment)	50.95
3.	Loss of land (equipment path)	.43
4.	Operating costs:	
	Fuel	11.50
	Repairs and maintenance	5.91
	Labor	1.00
5.	Added costs of production	14.40
	TOTAL COST PER ACRE	$84.19

Thus, for irrigation from the Dakota Sandstone aquifer, fixed costs are increased by $9.72/acre, variable costs are

[1]The pumping water level is the appropriate figure to use for feet of lift required for irrigation.

[2]James Wiegand, Deputy Water Commissioner of Iowa, personal communication, 1977.

increased by \$5.22/acre and total costs are increased by approximately \$14.94/acre over irrigation from a shallow alluvial aquifer.

III. APPLICATION OF THE MODEL TO WATER ALLOCATION PROBLEMS IN IOWA

A. The Long Term Profitability of Irrigation in Iowa

As shown in Table 2, the average costs of raising crops on the bottomlands under irrigation exceed dryland crop expenses by $70 to $80 per acre. Costs at upland sites requiring Dakota wells will be approximately $15 per acre more than the bottomland sites. With these costs, irrigation will not be profitable on the "average" soils used in the Thompson and Shaw models. The soils modeled in those studies are average crop soils for Northwest Iowa in terms of infiltration rate, permeability, and available water holding capacity. The average yield increases predicted by Thompson's and Shaw's models are 14.5 and 17.5 bu/acre, respectively. Because irrigation is also able to increase yields by permitting higher plant densities and rates of fertilization, actual yield increases will probably exceed those predicted in the two models. Since these effects cannot be incorporated in the models costs associated with these practices are excluded from the costs in calculating the profitability of irrigation. The returns from irrigation predicted by the two models are shown in Table 3 for two hypothetical prices of corn.

Tabl3 3. Costs and returns of irrigation for two prices of corn[a]

Corn price (dollars)	Yield increase (bushels)	Increase in revenue (dollars)	Cost for bottomland site (dollars)	Cost for an upland site (dollars)
$2.00/bu	14.5	29.00	51.01	65.95
$2.00/bu	17.5	35.00	51.01	65.95
$2.75/bu	14.5	39.88	51.01	65.95
$2.75/bu	17.5	48.13	51.01	65.95

[a]The costs exceed the returns in all cases.

The eight irrigators interviewed reported yield increases in excess of those predicted by Thompson's and Shaw's models:[1]

	Predicted by Shaw's model	Predicted by Thompson's model	Range of yield increases
1976	60.1 bu/acre	28.7 bu/acre	60-130 bu/acre
1977	15.6 bu/acre	7.3 bu/acre	40- 80 bu/acre

Thus, irrigation was profitable in both 1976 and 1977 even at the low end of the range of yield increases reported, and at this year's low corn price:

$2.00/bu x 40 bu/acre = $80/acre

An $80 return per acre is sufficient to offset the average cost of irrigation, $78.40. It is enlightening to note that even in a year of ample rainfall, as 1977 was in Northwest Iowa, irrigators were able to realize a profit on their investment. According to Thompson's model, there were only six years in the period from 1928 to 1976 more favorable to crop growth in terms of rainfall than 1977.

As already stated, there is not enough data available to predict accurately the yield increases these irrigators can expect over a long period of time. A rough estimate can be made, however, by noting that the average yield increase predicted by Thompson's model is 14.5 bu/acre. This is

[1]Source: personal interviews with irrigators.

close to the mean of the predicted yield increases in 1976 (28.7 bu/acre) and 1977 (7.3 bu/acre). It is reasonable to assume that in an average year, the irrigators interviewed would also have yield increases close to the mean of their 1976 and 1977 figures. This would put their expected long term yield increases in a range from 50 to 105 bu/acre, depending upon the soil type.

A discrepancy exists between the yield increases predicted by Thompson's and Shaw's models on the one hand, and those realized by the irrigators interviewed, on the other. This is due to several factors:

1. Soils:

All of the irrigators interviewed were located in the floodplain of a small river or creek. Most of the soils were coarse textured, typically silty or fine sandy loams. Many of the soils were extremely shallow, some only 8 to 10 inches deep, overlying sand and gravel deposits. Instead of having a "bank" of soil moisture in the subsoil, many of these river bottom soils release excess moisture to the alluvial aquifer below. On these soils a total crop failure due to drought occurs fairly frequently; one irrigator estimated that this occurred once every five years. The largest yield increases shown in Figure 9 reflect crop failures on the unirrigated land.

2. Fertilization:

All but one of the irrigators interviewed applied liquid nitrogen through their irrigation systems. This is the only way to apply nitrogen late in the season and it may be a more economical and effective way to apply it at any time of the year. In any case, the liquid nitrogen appears to have been an important factor in the large yield increases reported.

3. Problems with the models:

Neither of the two models made any allowance for the increased plant densities or increased fertilization characteristic of irrigated agriculture. In addition, the linear nature of the regression equation used in Thompson's model may have underpredicted potential yield increases by obscuring nonlinear dependencies and joint effects. (Joint effects were excluded from the regression equation because they were not found to be statistically significant.)

A fourth reason might be inaccuracy of the yield increases reported in the interviews.

Accepting all of these problems as they are, it is possible to calculate average return per acre for irrigation. These figures are presented in Table 3 and Figure 19. Returns for 12 of the sites (two fields on one farm had to be averaged together) as well as returns under Thompson's and Shaw's models are shown. The yield increases used for

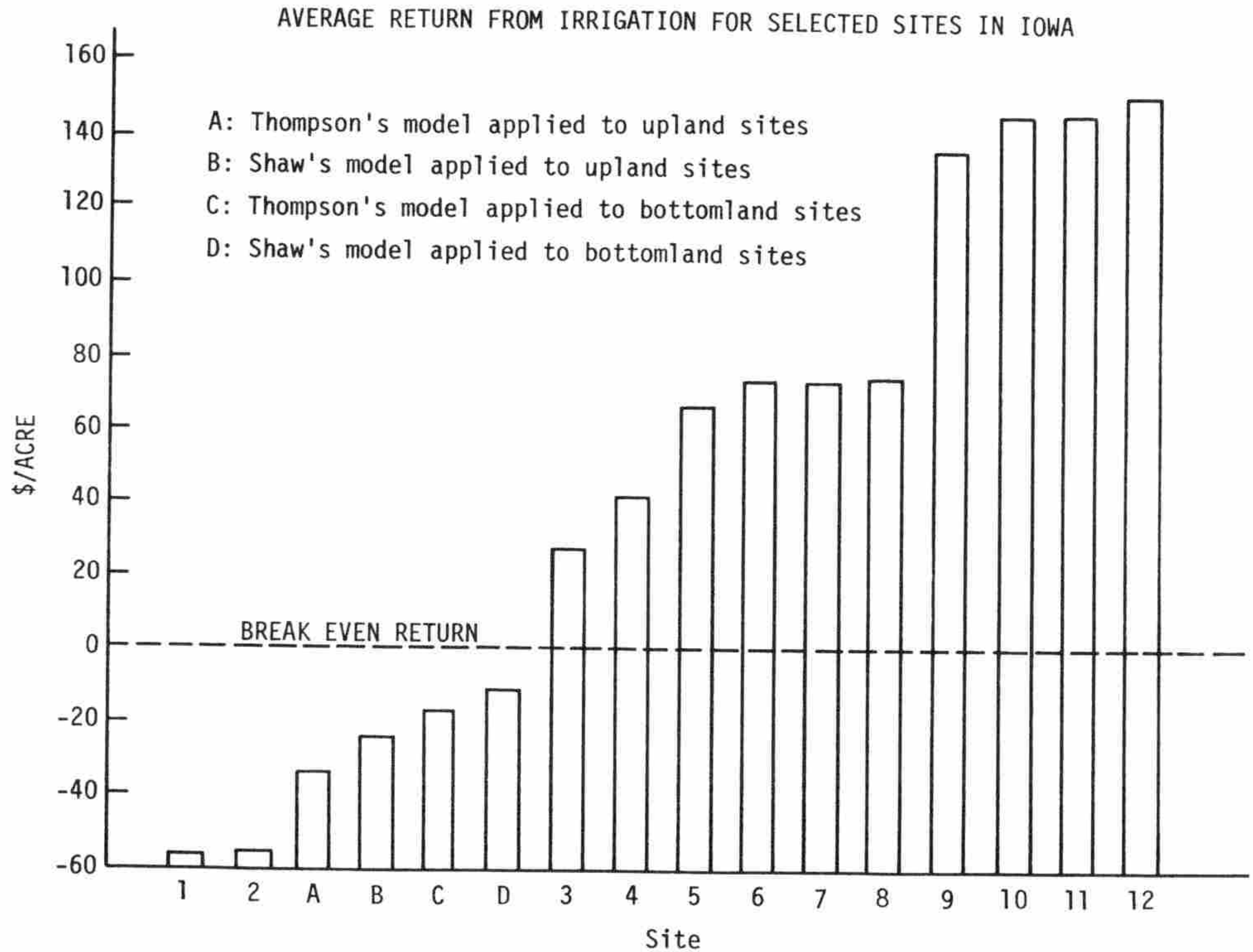

Figure 19. Average return from irrigation for selected sites in Iowa

the 12 sites are the means of the 1976 and 1977 yield increases. The irrigation costs used are $78 per acre for the irrigators interviewed and two figures, $51 (for bottomland sites) and $66 (for upland sites) for the Thompson and Shaw models which do not assume extra fertilizer and seed for irrigated land.

The most important conclusion which can be gained from Table 3 and Figure 19 is that quite special conditions must exist if irrigation is to be profitable in Northwest Iowa. The negative returns on sites 1 and 2 and those predicted by the Thompson and Shaw models show that for average conditions irrigation is normally unprofitable. The break-even price of corn required to justify irrigation under Shaw's predicted 17.5 bu/acre yield increase is $2.91/bu on the bottomlands and $3.77 for upland sites.

The irrigators interviewed were all operating under special conditions. Because they were in floodplains, the soil was often coarse and the subsoil absent. In addition, they had a good supply of water at comparatively shallow depths below their farms. Unlike most farmers, who rely upon stored subsoil moisture for the long periods between rains in July and August, these irrigators used the alluvial aquifer below their farms for supplemental moisture. A study of the soils overlying alluvial aquifers and buried channels would probably solve the problem of which sites have the characteristics required for irrigation to be profitable.

B. The Value Product of Water in Irrigation

Water use figures for 1977 for the 8 irrigators interviewed are presented in Table 4. The average application was 6.1 inches. The Thompson model predicts an optimum application of 3.6 inches in 1977. For the average year, it predicts an optimum application of 5.8 inches for the season. It is unrealistic to expect irrigators to limit their applications to those suggested by the model. A theoretical model will assume that water is applied at exactly the best time and at the optimum rate and droplet size.

Data from an experimental farm conducting irrigation research in Central Iowa from 1954 through 1963 (4) show a mean annual application of 8.75 inches. Charlson (5) uses a figure of 7 inches as the mean annual application, while Eisenhauer and Fischbach (7) and Beer and Wiersma (3) use a figure of 12 inches. Barnard and Dent (2) calculated a weighted application rate based on distribution methods currently being used in Iowa. The figure they arrived at is 13.1 inches. Firm data are lacking on the actual amount of water being used by irrigators in Iowa. After inspecting many water use reports and interviewing several irrigators,

Table 4. Irrigated and unirrigated yields and amount of water applied for 13 sites in 1977[a]

Site	Irrigated Yield	Unirrigated[b] Yield	Number of applications			Amount per application (inches)	Total amount applied (inches)
			June	July	August		
1	120	115	0	3	2	1	5
2	110	90	½	1½	0	1½	3
3	110	70	½	1½	0	1½	3
4	172	130	2	4	4	1	10
5	145	100	2	3	1	1½	10
6	160	115	0	3	2	1	5
7	150	100	2	3	2	1	7
8	130	75	1½	3	1½	1¼	7.5
9	160	100	2	4	4	1	10
10	120	55	0	2	2	1½	6
11	130	60	0	4	3+2 in Sept.	2½(?)	22.5(?)
12	150	70	2	3	2	1	7
13	200	75	1½	3	1½	1¼	7.5

[a]Source: personal interviews with irrigators.

[b]Unirrigated yields were estimated from corners of irrigated fields, adjacent fields, and occasionally from a neighbors field.

the average annual application has been estimated in this study to be 9 inches. This figure can be used in an input-output model as the fixed amount of the water input required to irrigate an acre of corn in Iowa.

The average values of irrigation water calculated from the irrigators interviewed and the Thompson and Shaw models are shown in the right hand column of Table 3. The figures range from $0 to $16.71 per acre inch of water. The same assumptions used for computing the net revenue from irrigation pertain to these results. It is difficult to find a basis of comparison for these figures. Tijoriwala, Martin, and Bower (48) developed an input-output model for the economy of Arizona. In their study, they computed the personal income generated in various sectors of the economy per unit of water used. The figures for several of these sectors of the economy are reproduced in Table 5.

The data in this table are not comparable with the values of water computed in the study. The former are measures of the personal income generated through the use of water in a particular industry. They are calculated by summing the wages paid, depreciation (representing the cost of the use of a capital good), profits, interest, and taxes and dividing by the amount of water used (48). These figures can also be thought of as the value added per unit of water, or the income generating capacity of the water (48).

Table 5. Personal income per acre-foot of water intake in Arizona sectors and rank of each, 1958[a]

Sector	Dollars of personal income[b] per acre/foot	Sector rank[c]
Food and feed grains	14	10
Forage crops	18	9
High value intensive crops[d]	80	8
Livestock and poultry	1,953	6
Agricultural processing industries	15,332	3
Utilities	2,886	5
Mining	3,248	4
Primary metals	1,685	7
Manufacturing	82,301	1
Trade, transportation and services	60,761	2

[a]Table taken from Tijoriwala, Martin and Bower (48) as adapted by Young and Martin (53).

[b]Personal income defined to include wages, salaries, rents, profits and interest.

[c]Ranked from highest to lowest value added.

[d]Includes cotton, vegetables, citrus and other fruits.

In order to compare the figures generated in this study with the Arizona study, the following procedure can be used to separate out the intermediate costs (transfer to other industries):

Total Revenue = Total payments to factors

= Payments to other industries + a residual

This residual represents the value added by the industry under study, because payments to other industries are excluded. In the case of irrigation, the payments to other industries which must be excluded are fuel costs, repair and maintenance, insurance, fertilizer, and seed. These payments must be subtracted from total revenue (not total cost) in order to include profits in the value added. This difference is then divided by the amount of water used in order to calculate the personal income generated per unit of water by irrigation in Iowa. These results are performed in Table 6 (assuming an average annual application of 9 inches).

The personal income generated per acre foot of water for the selected sites in Northwest Iowa and as predicted by Thompson's and Shaw's models can be contrasted with the figure of $14 per acre foot in the food and grain sector in the Arizona study (48). The figures are generally higher in this study. This is caused in part by the fact that the

Table 6. Personal income generated per unit of water[a]

Site	Revenue from extra yield ($)	Transfers to others industries ($)	Value added by irrigation ($)	Personal income generated per acre-foot of water ($)
1	$22.50	$40.96	$0	$0
2	22.50	40.96	0	0
3	98.88	40.96	57.92	77.23
4	120.38	40.96	79.42	105.89
5	146.25	40.96	105.29	140.39
6	151.88	40.96	110.92	147.89
7	151.88	40.96	110.92	147.89
8	151.88	40.96	110.92	147.89
9 10	216.00	40.96	175.04	233.39
11	225.00	40.96	184.04	245.39
12	225.00	40.96	184.04	245.39
13	228.38	40.96	187.42	249.89
Thompson's model (bottomlands)	32.63	13.56	19.07	25.43
Thompson's model (upland)	32.63	18.66	13.97	18.63
Shaw's model (bottomland)	39.38	13.56	25.82	34.43
Shaw's model (upland)	39.38	18.66	20.72	27.63

[a]All figures are per acre. Values are generated from interview data using methods of Tijoriwala, Martin and Bower (48).

average annual application in Iowa is estimated at nine inches, while in Arizona it exceeds 45 inches (48). Thus, the majority of the water which the crops receive in Iowa is rainwater which is free, while all the value accrues to the irrigation water applied. A second reason for the greater income generating power of irrigation water in Iowa is the exceptional nature of the sites studied. As already mentioned, several inches of water applied can make the difference between a crop failure and a bumper crop on the soils in question.

In addition to these two reasons, it must be noted that the two sets of figures are still not strictly comparable.

In the Arizona study, the value added is calculated in terms of the entire farming operation, while in this study the figures represent the value added by the irrigation system over dryland farming. This difference in approach will cause a bias in the results in favor of the Iowa figures. Further study of this problem and all the others alluded to earlier are needed before it can be concluded that irrigation water has greater income generating power in Iowa than in Arizona. Because irrigation was not specifically included among the production sectors in the Barnard and Dent study (2), no direct comparisons can be made with the value added by water use for agricultural purposes in their study.

IV. IMPLICATIONS OF FINDINGS FOR POLICY AND FUTURE RESEARCH NEEDS

Policy implications pertain to several categories. These categories are listed according to the cost to society with which they are associated. They are: competition for scarce water supplies; aquifer depletion, deterioration of water quality; and coordination of Iowa's water policy with national goals.

A. Competition for Scarce Water Supplies

The body entrusted with the task of allocating water resources in Iowa is the Iowa Natural Resources Council (19). The legal basis for this authority lies in the 1957 Water Law, Section 455A of the Iowa Code. Current policy at the council is to grant a permit for water withdrawals in most cases if the applicant can show that the water will be put to a beneficial use and that certain conditions are met. The most important of these conditions is that there be no evidence that the proposed well will adversely affect another well in the vicinity. This is the chief safeguard against competition for scarce water supplies under current policy. Other conditions for granting a permit require that the permit comply with other regulations such as reporting annual water use.

Until now, the Water Commissioner has not discriminated between water uses on the basis of the level of beneficiality (16). The fact that an applicant can demonstrate that the proposed use of water is beneficial is sufficient for a permit to be granted. In support of this interpretation of the statute are passages in Sec. 455A.20 of the Iowa Code (as paraphrased by Hines) "which directs the Commissioner to grant the permit if certain findings are favorable to the applicant" (16, p. 36) and in 455A.21 "which directs that the standard for determining the disposition of permit applications is one of beneficial use" (16). A beneficial use is defined in the statute as "a use which accrues to the benefit of the user". Hines notes that this definition is so broad that it includes "all uses not wasteful or causing pollution (16, p. 36).

The Water Commissioner has been able to follow this policy because competition for water supplies has not as yet been a serious problem in Iowa. In the few situations where well interference has been a problem, it has occurred between regulated and nonregulated users. The law states that in such a circumstance the nonregulated user has a higher priority for the supply source (19). No permit has been revoked or denied because of competition between regulated uses.

It is not safe to assume that this situation will continue. Water use has been increasing steadily in recent years. Especially prominent has been the increase in applications for irrigation permits. The time will certainly come when a substantial number of projected or actual water withdrawals will conflict with other uses. Policy equipped to deal with these problems should be formulated before the problem actually occurs.

What types of problems can be anticipated? As described in Appendix B, a likely scenario for competition for scarce water supplies would be in a shallow alluvial aquifer in northwest or western Iowa. If a substantial number of farms on the floodplain of one of the small streams in the area started irrigating, it is possible that a regional lowering of the water table could occur in dry years. This could hurt many of the wells in the area. This type of regional competition is characterized by the outflow of water from an area exceeding the inflow. While there is no evidence that this has happened as yet, there is room for considerable expansion of irrigation on many floodplains. The current policy of granting permits unless interference can be proven to exist is insufficient because most of the permits recently approved will not have irrigation systems in operation for a few years (21). The real question is whether the small alluvial aquifer system can support so many systems and that cannot be answered until most of the irrigators start pumping. The point is not being made that problems will definitely occur in a few years time. It is simply that the policy should anticipate the problem.

Upland sites and the Missouri Bottomlands area have received little attention in this study. In the former case, this is because there has been comparatively little interest in irrigation outside the floodplains. The results of this study show that this is not, in general, a profitable venture. In the latter case, it is unlikely that competition for water supplies will occur because of the vast quantity of water in the formation (22).

The nature of water competition in Iowa suggests a local, as opposed to state-wide, approach to the problem. Because interbasin water transfers and long distance transport of water are not significant aspects of Iowa's water use situation, the problem will probably remain confined to small areas or river basins.

B. Policy Alternatives

One of the most fundamental questions regarding competition for scarce water supplies is the legality of using economic cirteria for allocating water. Hines (16) has explored this problem in detail and concludes that the Iowa Water Law is ambiguous on this point. The statute states that "the water resources of the state be put to beneficial use to the fullest extent of which they are capable" (16). As Hines comments, "the patent difficulty with such lofty statements of policy is their failure to provide any hint of the frame of reference by which the beneficiality of a use is to be judged" (16, p. 35). The statute also requires that the Natural Resources Council develop a plan for the optimum water use in Iowa including provisions for allocation and protection of the states water resources (16).

Hines suggests that "coupling the idea of a comprehensive state plan with the policy declarations in favor of optimum water use suggest that a sound argument could be made that the legislature intended the formulation of standards for distinguishing between uses on the basis of their respective beneficialness" (16, p. 35). If the Council did rank beneficial uses, there are two ways in which these priorities could be used. High priority water users could receive preference over others in the granting of permits, or low priority users could receive permits subject to the condition that there be enough water for high priority users. There are certain practical difficulties associated with either of these systems. Of the two, the disadvantages are considerably more serious for the first system.

The problem with the first system is that it is difficult to predict the effects of a proposed water withdrawal before it actually takes place and it is impossible to predict future water use in an area. Once a permit is granted and the investments associated with the water use are made it would not be reasonable to revoke that permit if it interfered with a higher value use. In the absence of an overall plan for a region, the procedure would probably revert back to the current "first come-first served" system. All applications are not received at the same time and some action must be taken when they are received.

The second system would involve suspending water withdrawal rights for a low priority user if the water supply of a high priority user were threatened. Under this system, a low priority water user would have a lower certainty of expectations associated with the investment. Under the system guidelines would have to be worked out if more low or high value water users applied for permits. It is not clear whether a high value water user arriving in an area could be guaranteed use of water at all times at the expense of long established low value water users. As an example, an irrigator might be issued a permit subject to the condition that water withdrawal rights would be suspended if a municipal or industrial water supply were threatened.

The question would have to be settled concerning the proper procedure to follow as more factories moved into the area, as municipalities drilled new wells, and as more farmers applied for irrigation permits. Would the original irrigator experience a continually decreasing certainty of expectations as these events took place? If the recharge characteristics of the aquifer were known, permits could be limited to the amount of water available in dry years. This amount could take the form of a frequency-duration figure, such as the maximum amount of water available 90% of the time between June 1 and September 1. If the number of permits were limited in this way, some method would have to be devised to ensure that all the permits were actually making use of the water.

Even if priorities were established for various water uses, it is not clear that economic criteria would be used for establishing the priorities. Other criteria which could be used by the Council include "recognized societal goals" (16, p. 35) or environmental concerns. Economic criteria, such as income generated per unit of water would probably play some role in ranking water uses, however. As shown in Chapter III, irrigation appears to have the lowest value of any of the major uses in Iowa. This conclusion is by no means definite and requires considerably more study. In this case, irrigation would be assigned the lowest priority if economic criteria were used for ranking uses. This would not solve all the problems in many of the river valleys in western Iowa. A typical stretch of a river valley would have one or two municipal and industrial users, and a large number of domestic wells and irrigators. The highest priority users are the domestic wells. Domestic water use is a nonregulated use and under the existing law nonregulated uses have priority over regulated uses (19). The municipal and industrial users would receive the next highest priority, according to the priorities set by the Council. But lumped into the lowest priority group would be a large number of irrigators, using by far the greatest amount of water. It would be necessary to establish some form or allocation among those irrigators.

One approach to this problem would be to adopt the same type of system currently being used for stream irrigators. Regulated water users must stop withdrawing water from a stream when the streamflow falls to a predetermined level known as the protected low flow. This level is set at the flow which is maintained 84% of the time from May through October. When streamflow reaches a level somewhat above the protected low flow, all the irrigators along a certain stretch of the stream must meet and work out a plan to set pumping hours for each irrigator. This is done to prevent streamflow from falling below the protected level as a result of their pumping. This type of rationing system could be adapted to irrigators pumping from a shallow alluvial system. Under such a system, irrigators could decide upon pumping hours after the water table fell below a certain level. An alluvial groundwater system differs from a stream in that during dry periods it would have a deficit of water reserves rather than flow. The period of recharge for an alluvial system is usually measured in months, not hours, which would defeat the purpose of setting pumping hours. In addition, the period of time required for the full recharge of a high priority well would probably be too long for a system of setting pumping hours to accomplish much. In conclusion, the water rationing system used by stream irrigators is probably not adaptable to alluvial systems.

Another option for the Natural Resources Council would be to extend rankings of beneficial water uses to irrigation on different soil types. It is evident from this study that irrigation has the greatest value on coarse textured soils and especially on those soils underlain by gravel (lacking subsoil). Proceeding along these lines, a study could be made of the water resources and soils in a particular river valley. Such a study would show the expected yield increases for most of the soils in the valley and estimate the amount of water normally available in the aquifer. A local or state committee could then decide how much irrigation is desirable and on which soils it should be permitted. Since this system would require such a long and involved study it is not suggested as an immediate possibility but rather as an option which may be required some time in the future.

One aspect of the system outlined above which may have immediate relevance is the possibility of restricting irrigation to certain soil types. In order to do this, a complete study relating yield increases and pumping costs to soil type and location would have to be carried out. Such a study would not be especially difficult, however. From this study, it can be seen that in certain exceptional cases irrigation can be extremely profitable, but for the average site in Iowa, irrigation cannot be justified financially. It is doubtful that irrigation on such sites could be considered a beneficial use. A statement encouraging irrigation on sites meeting certain requirements and discouraging it on others could be incorporated in a state water plan.

An alternative to all of these possibilities would be to charge a price for water. Charging users for water is superior to other systems for several reasons:

1. This study and others (21,48) illustrate that the net revenue from irrigation on most sites is so low that water use fees will discourage many potential irrigators from buying rigs. This is the classic function of the price system in allocating a scarce resource.

2. If only serious irrigators apply for permits, a much more accurate analysis of the ability of the aquifer to sustain enough yield for an extra irrigation system can be made. A permit could be granted with considerably more certainty that the water source is sufficient for the permittee and his neighbors than is now the case. Observation wells are currently being used for this purpose, but they are useless for analysis unless a substantial number of permittees in the vicinity have been pumping.

3. The state's water users are currently benefiting from the Iowa Natural Resources Council, an agency which resolves disputes among water users, avoids disputes by rejecting applications that are likely to disrupt someone else's water supply and helps monitor water use patterns for efficient planning. Most of these benefits accure to the permittees, not to the general public; it is only reasonable that the permittees should be charged with the costs of operating this bureaucracy. This would be most equitably done by charging users according to the quantity of water they are allocated.

4. A water pricing system which will lead to efficient resource allocation in the long run is required. The arbitrarily chosen price of \$2.00 per acre-foot suggested by Council Chairman Merwin Dougal is probably below the theoretical optimum of marginal cost pricing, but it represents a step in that direction. In marginal cost pricing, the price of water would reflect the social costs associated with water use. There would include aquifer depletion, maintenance of a water allocation authority, and diminished environmental conditions and recreational possibilities.

The main reason that the price of water has been maintained at zero is that the ownership of land has traditionally been associated with a "bundle of rights", one of which was control of the water beneath the soil. The counterpart of groundwater ownership for surface water has been either riparian rights or prior appropriations, both of which treat water as a free good. Through the years, the bundle of rights associated with land ownership has been eroded away to the point where a landowner no longer has control of the space above and below his land "from the heavens above to hell below". Examples of these eroding rights are placing control of the airspace above land into the hands of the FAA, and the Iowa Water Permit Law for withdrawals of water exceeding 5,000 gal. per day. The government is as yet unwilling to take the next step of charging landowners for the water they withdraw. Perhaps the landowners would be less opposed to being charged for the water if made aware of the fact that in most cases they are pumping at least some of the water from under their neighbors' land.

The results of this study illustrate that the irrigators interviewed would be able to afford the $2.00 per acre-foot water charge proposed by Dougal. Comparing this charge with the returns per acre-inch of water applied (see Table 6) shows that only the most marginal irrigators could not afford to pay it. Charging this price for water would increase the cost of irrigating by about 2.5%. A major benefit which would arise from charging a price for water would probably be to eliminate a large amount of the backlog for irrigation permits at the Natural Resources Council.

C. Aquifer Depletion

The results of this study suggest that irrigation is not profitable from the deeper aquifers. The only exceptions would be on some especially coarse textured soils not normally found on upland sites. The Iowa Water Law states that "the water resources of the state be put to beneficial use to the fullest extent of which they are capable" (19) and that the state "shall take such measures as shall effectuate full utilization and protection of the water resources of the state of Iowa" (19). It is difficult to reconcile these provisions with irrigation from the Dakota Sandstone or Jordan Sandstone aquifers. Future generations of Iowans will bear the cost of marginal or submarginal use of this water today. The current ban on irrigation from these squifers should remain in effect at least until accurate recharge figures have been obtained.

D. Deterioration of Water Quality

Groundwater contamination, especially by nitrates, has frequently been cited as one of the harmful effects of irrigation (12). Research to date has failed to show any evidence of increased nitrate accumulation in the aquifer underlying the heavily irrigated Missouri bottomlands (12). Hallberg notes however, that "the potential for nitrate contamination is only of concern where highly permeable soils are irrigated over shallow aquifers" (12, p. 32). As this study and the number of applications received by the Natural Resources Council indicate, these are precisely the sites likely to experience an expansion in irrigation. Because of this, the question of groundwater contamination cannot be ignored. Nitrate contamination can be kept to a minimum, however, by avoiding excessive applications of fertilizer or water (12). Beer, Shrader and Schwanke (4) have shown that no yield increases resulted from increasing soil moisture above 60% of field capacity. Hallberg states that "significant leaching cannot take place at this moisture content and this level can be maintained by monitoring rainfall and knowing the approximate water-holding capacity of the soil" (12, p. 36). Hallberg goes on to point out that if proper farm management practices are followed, irrigation can actually reduce nitrate contamination. This is due to the fact that in climatically poor years significant amounts of side-dressed and broadcast fertilizer will not be taken up by the plant and will leach down to the groundwater in the period following harvest (12).

In consideration of these arguments, the indications are that irrigation does not greatly increase the possibility of groundwater contamination. In areas where this may be a serious concern, permit determinations should include a clause limiting the amount of fertilizer applied either through the system or dry. It may also be necessary to limit the amount of water applied in a season in order to keep soil moisture below 60% of field capacity if the problem persists.

E. Coordination of Iowa's Water Policy with the Nation's Energy Policy and Agricultural Policy

It is beyond the scope of this study to deal with this problem in any detail. Both the energy policy and the agricultural policy are important considerations which should influence a state policy on irrigation. By encouraging irrigation, the state would be encouraging a type of agriculture which increases yields and uses large amounts of energy at a time when the federal government is considering a set-aside program and is asking for a commitment representing the moral equivalent of war to reduce energy consumption. It is enlightening to note that the diesel fuel required to apply 6 to 12 inches of water with a conventional center pivot system (the average for Iowa is close to 11 inches) will increase energy consumption from four to eight times over nonirrigated energy use per acre(12). Hallberg points out that "studies in Nebraska have shown that 43% of the energy devoted to agriculture in Nebraska is consumed in pumping water for irrigation" (12, p. 38).

Of course, the problem of energy use for irrigation is also related to the problem of regulated energy prices. Nevertheless, it is important to keep in mind that by keeping the price of water at zero, an economy based on the premise that water supplies are unlimited is being stimulated.

The incomes of irrigation dealers and related services are also affected by Iowa's water policy.

F. Future Research Needs

The most complete study on irrigation in Iowa published to date is the volume entitled Irrigation in Iowa by Hallberg, Horick and Koch (1976) (12). Hallberg, who compiled the main body of the work listed nine research topics. The basis for this study indicates one of these research needs. It was described as follows:

> Short-term statistical analysis to analyze the costs or benefits irrigation might have had over the past 50 to 75 years in Iowa. This would provide a much better base for evaluation of the real economic potential of irrigation (12, p. 41).

Other research needs listed by Hallberg are oriented toward the hydrogeologist, the agronomist, and the agricultural engineer and will not be repeated here (12, p. 41).

Another major work regarding agricultural water use in Iowa is the Agricultural Task Force Report written by the Iowa Natural Resources Council and the Soil Conservation Service in 1977 (21). In a vein similar to Hallberg, the task force stated that "historical studies of climatic variability should be completed to better define climatic trends, fluctuations, cycles, and extreme values that affect agriculture" (21, p. 222).

In this study, several questions associated with the long term profitability of irrigation in Iowa have been raised and discussed, but many more questions remain to be answered. The most important indication which has been suggested in this study is that irrigation may not be generally profitable on the farms studied. The most important research need is to find a method of predicting yield increases on specific soils in Iowa. Probably some adaptation of Shaw's method or Thompson's model could be used to accomplish this. By checking the permit files at the Iowa Natural Resources Council the soils which are likely to be irrigated in the near future could be determined. Characteristics of these soils, especially available water holding capacity in the first four feet and corn suitability rating could be found either through the soil surveys or when these are not available, by field experiments. If a functional relationship between one or more of these soil characteristics and yield increses from irrigation could be established, much of the uncertainty facing potential irrigators and policymakers could be eliminated. With a firm understanding of how much income would be added to the state of Iowa as more acres were brought into irrigation, it would be easier to adopt a comprehensive irrigation policy.

A second research need is to determine which areas are likely to experience competition for water supplies before the problem occurs. In this study it was pointed out that competition was likely to occur in the floodplains of the small rivers of western Iowa. Irrigators interviewed in the Rock River Valley argued that this would not occur because most of the land with sufficient groundwater supplies were already being irrigated. A hydrogeologic study of one or more of these floodplains, perhaps coupled with a study of their soils could indicate whether water scarcity is likely to become a problem. A minimum research requirement in this area would be to estimate the ratio of irrigated to unirrigated land on the river bottom. A more elaborate study could relate available water supplies to the optimum development of the region. Most of these studies would have to be interdisciplinary.

A third research need is to generate data for the value of water in different uses in Iowa. The best basis of comparison currently available are the Arizona figures appearing in Martin and Young's article (24). Personal income generated per unit of water in Iowa should be available for most water uses in the state. These figures were conspicuously missing from the task force reports. They are essential for efficient planning in documents such as the Iowa Water Plan (not yet written).

When enough data have been generated by the first two research needs listed, it will be possible to estimate the marginal value product curve of irrigation water as more acres are irrigated. The first study can determine the value of irrigation on different soils; the second study is needed to establish a continuum of the acreage likely to be irrigated, ranked from most profitable to least profitable.

V. CONCLUSIONS

Most of the conclusions have been stated in Chapters III and IV. A brief review of these is presented here.

The most important indication reached is that irrigation appears to be an economically useable proposition only on a limited number of sites. This indication is borne out by the Thompson model, the Shaw model and the limited interview results presented in Chapters II and III. Excluding concl unusual sites, the value product of water for irrigation is very low (Table 6, Figure 19).

Although the problem requires further study, the chief characteristics required for a site to provide a concl large value product of water, are a coarse textured subsoil and shallow pumping depths. Such sites may be found in the floodplains of Iowa's rivers and streams (18). The applications for irrigation permits received by the Iowa Natural Resources Council bear out the fact that irrigation is proliferating in such areas (21).

Because river valleys also tend to be centers for commercial and municipal activity, intrasectoral and intersectoral competition for water can be anticipated in these areas. The most promising policy directed toward this problem would appear to be the charging of users for water (along the lines of Dougal's proposal).

The methodology used in predicting the average yield increases from irrigation has several flaws which are alluded to in detail in Chapter II. It nonetheless represents an improvement over previous attempts at estimating average irrigated yields because it takes into account many years of climatic data. The relative merits of the Thompson versus the Shaw approaches are open to debate. In favor of the Thompson approach is the greater number of years of data available (50 years) and the fact that the results can be applied to a large area. In favor of the Shaw approach is the simplicity and inherent accuracy of the approach. Its disadvantages are that data are confined to a fewer number of years (18 for most locations) and the fact that the method yields results strictly applicable only to a specific location.

The greatest research need at this point is to determine functional relationships between soils, climate, and yield increases from irrigation. Such a study could lead to an estimation of the value product of water in irrigation, classified according to site characteristics. This is perhaps the most immediate need facing Iowa's water policymakers. In the longer run, estimates of the value product of water in all uses are required for achieving policy goals.

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VII. APPENDIX A: COSTS TO SOCIETY OF WATER USE

This discussion is qualitative in nature. The absence of dollar values assigned to each of the costs does not diminish their importance. The costs are real, and will shift the marginal and average cost curves just as surely as pumping costs or the depreciation on an irrigation rig.

A. Aquifer Depletion

This is perhaps the most obvious cost associated with the use of groundwater. Aquifer depletion is typical of a common and difficult problem in resource economics. It is related to the temporal effects discussed earlier. Several methods have been suggested for determining the optimum rate of use for a nonrenewable, or slowly renewable resource. Hirschleifer et al. (17), for example, has suggested a method of maximizing value over time using a discount rate of zero. Such an approach would avoid favoring one generation over another.

Any mathematical analysis of aquifer depletion requires good technical coefficients. Although some digital modeling of the Jordan aquifer has been done, sufficiently accurate data for the major aquifers in Iowa are not available. The Iowa Task Force Report on Water Availability gives estimates of recharge rates in a range usually equivalent to one order of magnitude (example: .2 to 2 million acre-ft per year). The extent, depth, and characteristics of the water bearing formation are also missing for some areas.

Fortunately, this type of study is not crucial to the development of a water plan for Iowa. A discussion of each of the major aquifers will demonstrate that policy choices are actually quite limited.

In Iowa, aquifers may be divided into three general categories:

1. Bedrock aquifers with little or no recharge;
2. bedrock aquifers with fair to good recharge; and
3. Pleistocene sands and gravels with good recharge.

Long term aquifer depletion is a problem associated with the first group listed. The most important aquifers in the first group are the aquifers of the Cambro-Ordovician formation (especially the Jordan Sandstone).

In certain parts of the state, aquifers in the Mississippian or Silurian-Devorian systems are also essentially unrechargeable. All of them are being used for domestic (unregulated) uses, for municipal uses, and for industrial uses.[1] There is little irrigation currently

[1]The exact figures are available on computer data files at the Iowa Natural Resources Council.

underway from these squifers, and a temporary ban has been issued by the Iowa Natural Resources Council against the granting of any further permits for withdrawals for irrigation from the Jordan Sandstone or the Dakota Sandstone.

Until now, the high well drilling costs and pumping costs from these aquifers have discouraged irrigation. The unlikely circumstance of substantially higher corn prices and continued dry conditions may generate the economic incentive to use them for irrigation. The costs associated with irrigation from the Dakota Sandstone are presented later in this chapter. Good recharge data is lacking, but there are indications that large consumptive withdrawals will have an adverse effect on other water uses (22). Large local drops in piezometric pressures in both aquifers have occurred since wells were originally dug in the late 1800's, and in recent years when large consumptive withdrawals were made (22). It appears, that aquifer depletion will not be a problem in the foreseeable future if the bans on irrigation and once-through cooling remain in effect. This subject will be returned to in the Chapter IV (policy implications).

The chief cost to society of depletion of the Jordan or Dakota Sandstone aquifers is in depriving communities and individuals and industry of a reliable water supply source. Numerous municipalities currently rely on these squifers as their primary water source (23). Industry also uses large amounts of water from these aquifers (23). It would require a very large marginal revenue from irrigation or cooling uses to offset the cost of possibly losing these sources. As a basis of comparison, the water required to irrigate an acre of land is equivalent to the water withdrawals of a town of 10 to 12,000 or the water consumption of a town of 1 to 3,000 people (18).

The second type of aquifer listed was bedrock aquifers with fair to good recharge. The most important aquifer within this group is the Cedar Valley Limestone of the Silurian-Devonian System. This aquifer receives recharge from surface streams overlying the system (18). Quite a few applications have been received for irrigation from this aquifer. Hydro-geologic research is required to estimate its recharge characteristics to determine how serious a problem depletion of this aquifer could become. The location of this formation in northeast Iowa, which receives an average of 31" to 34" of rainfall per year, makes it a less pressing problem than if it were in western Iowa, since irrigation is less likely to proliferate in areas with a comparatively high rainfall.

The third category of groundwater listed was the pleistocene sands and gravels. These comprise the vast majority of groundwater irrigation sources in Iowa. Depletion of these aquifers is not generally a long term problem, since most of them receive good recharge from surface streams and infiltration. Short term depletion over a few years time can be a serious problem during drought periods but this is a problem of competition and allocation rather than depletion.

B. Competition for Water Supplies

Much attention has been devoted to the water allocation problems resulting from keeping water a free good. Is this problem relevant to the situation in Iowa now, or in the near future? Thus far competition for scarce water supplies has been minimal. In a few instances, municipalities have opposed the granting of irrigation permits because they were worried about possible effects on their supply source. In no case has a permit been denied because of interference with another water source (16). In a few instances, irrigation wells have adversely affected domestic wells and have been ordered to cease irrigation until the problem was resolved.[1] In other cases, industrial and irrigation wells have increased pumping costs for everyone by lowering the water table.[1] Most of these cases have been effectively handled

[1]Louis Gieseke, Water Commissioner of Iowa, personal communication, 1977.

by the permit system.

As yet, there has been no serious case of competition for water supplies on a regional level. There is evidence that this may occur in the future in the small alluvial aquifers and possibly the buried channels of Western Iowa.[1] Aquifers of this type capable of yielding 600 gpm or more are attractive to municipalities and irrigators as a low cost water source. The characteristically shallow pumping depths reduce both pumping costs and the dependability of the water supply.

The bulk of the backlog of applications for irrigation permits received by the Iowa Natural Resources Council during the 1974-1977 drought, even excluding applications from the Missouri Bottomlands, appeared to be from alluvial aquifers in Western Iowa.[1] Especially prominent among these were applications from farmers in the floodplains of the West Branch of the Des Moines River, the Rock River, the Nishnabotna River, and the Little Sioux River. Although firm data is lacking, it is difficult to assume that these aquifers will be able to sustain irrigation on a large percentage of farms in the floodplains.[1] When it cannot, there will be competing demands, both intra-sectoral and inter-

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[1]Louis Gieseke, Water Commissioner of Iowa, personal communication, 1977.

sectoral, on the resource.

Competition for scarce water supplies in shallow alluvial aquifers has been emphasized, but competition can also occur for surface water supplies, especially streams. The Iowa Natural Resources Council has determined that allowing streamflow to drop below a certain level constitutes an environmental hazard. This level is known as the protected low flow. When streamflow drops below this level, all regulated water users must cease further withdrawals. The current method of allocating stream water above the protected low flow is through a plan for pumping hours agreed upon by all irrigators pumping out of a certain reach of the stream. This seems to be a suitable method of allocation. Pumping from streams poses fewer economic problems than groundwater because almost all the water being withdrawn under the authority of a permit is used for irrigation (23). Allocation is greatly simplified because the bulk of the water has approximately the same value (in irrigation).

C. Diminished Recreational and Environmental Possibilities

This cost is mainly associated with streams, lakes, and reservoirs, though there may be some environmental problems caused by depletion of groundwater reserves (such as having a gaining stream transformed into a losing stream by a lowering of the water table).

In general, the protected low flow deals effectively with the problem of pumping a stream dry. It must, however, be recognized that there is a cost associated with pumping from a stream above the protected low flow. As an example, recreational activities such as swimming, fishing, and canoeing can be adversely affected well before a stream reaches the protected low flow. Some members of the Iowa Conservation Commission have also complained of ecological damage to a stream before it reaches the protected low flow.[1]

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[1] Statement contained in a letter from members of the Iowa Conservation Commission to the Iowa Natural Resources Council objecting to the granting of an irrigation permit in Fayette County.

VIII. APPENDIX B: IRRIGATION COSTS AS REPORTED IN THE INTERVIEWS WITH SELECTED IRRIGATORS

(Farms are coded 1 through 8):

A) Fixed costs:

1) Well:

Well	Depth (feet)	Year constructed	Cost (dollars)	cost/foot (dollars)
1	85	1956	850	10
	104	1956	1040	10
2	24	1976	1992	83
	40	1976	3520	88
3	50	1967	2500	50
4	60	1976	2700	45
5	50	1977	3300	66
6	200	1957	not known	
7	86	1974	2322	27
	81	1976	2268	28
8	uses a sand pit			

Costs shown include all costs associated with well construction. Average depth is 78 feet and the average cost is \$60/ft. (only wells constructed in 1976 and 1977 were averaged for costs).

Average total well cost = 78 ft. x \$50/ft. = \$4680.

2) Irrigation Rig:

	Type	Year purchased	Cost (dollars)	Miscellaneous
1.	Center Pivot	1975	25,000	Electric drive
	Center Pivot	1977	25,000	Electric drive
	+2000 ft. of underground pipe [$2.75/ft.			
2.	Center Pivot	1975	24,000	Electric drive
	Center Pivot	1976	40,000	Oil drive-cable suspended
3.	Center Pivot	1967	25,000	
4.	Tractor Mounted Gun	1975	6,000	Largest part of this was hose
	Tractor Mounted Gun	1975	6,000	
5.	Center Pivot	1974	30,000	Electric drive
6.	Tractor Mounted Gun	- self built		
7.	Center Pivot	1975	30,000	Aluminum-electric drive
	Center Pivot	1976	22,000	Steel-electric drive
	+1800 ft. of underground pipe @$2.50/ft.			
8.	Center Pivot	1976	30,000	Electric drive

Average of center pivot systems purchased since 1975:

$30,000 (excludes underground pipe).

3) Pump, Power Source, and Miscellaneous Fixed Costs:

Item	Year purchased	Cost (dollars)	Type
1. Pump	1956	1,500	5 stage line shaft turbine
	1956	1,800	6 stage line shaft turbine
Engine	1956	2,000	Diesel
2. Pump & motor	1976	5,000	30 H.P. motor 4 stage line shaft turbine pump
3. Pump & power source included in the cost of the rig			
4. Cost not shown			
5. Pump & motor	1977	8,700	For a 600 G.P.M. well includes control panel
6. Pump	1957	1,500	
7. Engine	1976	4,600	Diesel
alternator	1976	1,450	(needed for electric drive)
Cost of pump not known (line shaft turbine)			
8. Pump, pump-house, wiring, underground pipe, 60 H.P. motor	976	14,000	

Average for all required items purchased since 1976: $6,600

(excludes underground pipe).

B) Variable Costs:

1) Maintenance and Repair: These estimates are based on farm 1, 3, and 6, the only ones that have been irrigating long enough to give reliable estimates (at least 10 years). The major costs are changing the oil, filter, and gaskets on a regular basis and an occasional overhaul (approximately every five years).

Farm	Item	Cost	Average
1	Regular maintenance	\$144	
3	Regular maintenance	\$250	\$231
6	Regular maintenance	\$300	
1	Overhaul	\$1750	\$1975 ÷ 5 yrs. =
3	Overhaul	\$2200	\$395/year

\$231 + \$395 = \$626 for 135 acres or \$4.64/acre

2) Fuel Costs: Figures are for fuel use in 1977

Farm	Type of Fuel	Amount (gallons)	Cost (dollars)	Cost per unit
1	Diesel	1800	$810	$.45/gallon
7	Diesel	1944	875	$.45/gallon
2	Electric		945	$8/H.P.+$.022/KW=$7/A
3	Electric		1745	
5	Electric		1418	$1.50/acre-inch
8	Electric		806	$2.15/hour
6	Diesel (gun irrig.)	1800	810	$.45/gal

Average of 1 and 7: 1872 gals. $842 or $6.24/acre

Average of 2, 3, 5 and 8: $1229 or $9.10/acre.

Differences are due to different rate structures, the amount of pumping, and the amount of lift required.

3) Labor Costs: (excluding moving costs)

Farm	Manhours required (1977)
1	24
2	80
3	20
5	18
7	34.5
8	21
Average	33 @$4.00/hr. = $132 ÷ 135 acres
	= $.97 acre

Moving costs when one system is used for two fields:

Farm	Manhours required
2	48
3	22.5
5	25
7	31.5
Average	32 manhours

4) Extra costs of fertilizer, seed, and drying:

Farm	Fertilizer Cost	Seed Cost	Drying and Handling
1	7.14/acre	20% higher = 2.20/acre	$.14/bu
2	38/acre	33% higher = 2.87/acre	-
3	23/acre	33% higher = 3.50/acre	.10/bu
4	50/acre	not known	-
5	22/acre	33% higher = 4.00/acre	.12/bu
6	0/acre	20% higher = 2.20/acre	-
7	12.50/acre	9.00/acre	.10 bu
8	11/acre	1.00/acre	.07/bu
Ave.	$10.45/acre	3.54/acre	.11/bu

IX. APPENDIX C: INTERVIEW QUESTIONNAIRE

IRRIGATION SURVEY

General

1. How many tillable acres are there on the farm? _______ acres
   How many acres did you crop in 1977? _______ acres
   in 1976? _______ acres

2. How many of these acres did you irrigate in 1977? _______
   in 1976? _______

3. What was your source of water? Was it a stream, a well, or a reservoir?
   _________ stream ⟶ skip to Q. 6
   _________ well ⟶ ask Q. 4
   _________ reservoir ⟶ skip to Q. 5

4. a. How many irrigation wells are there on the farm? _______
   b. In what years were the well(s) drilled or dug? _______
   c. What is the capacity of the irrigation system? _______ gpm.
   d. Have the well(s) ever been pumped dry? _____ yes _____ no
   e. How much did the well cost? $_________ drilling or digging
      _________ casing
      _________ grouting
      _________ test hole
      _________ test pumping
      _________ miscellaneous
      _________ miscellaneous
      or $_________ TOTAL

5. a. In what year was the reservoir constructed? _______
   b. What is the storage volume of the reservoir? _______ acre ft.
      (Or if not known, what is the surface area and depth of the reservoir? _______ acres of surface area
      _______ ft. of depth)
   c. How much did it cost to construct the reservoir? $_______

6. At what rate do you usually pump? ________ gpm.

7. In what year did you purchase your irrigation system? ________
   Was the system installed the same year? yes ________ no ________
   If not, when was it installed? ____________________

8. What type of irrigation system are you using?

Center pivot	________	Water drive	________
Tractor mounted gun	________	Electric drive	________
Tow line	________		
Movable pipe	________		
Gravity flow	________		
Siphon tubes	________		
Other (specify)	______________________________		

9. What do you estimate the cost of the system was when purchased?

10. How many irrigation pumps are you using? ________

Type	Characteristics	Cost When Purchased
Line Shaft Turbine	________	________
Tractor mounted	________	________
Other	________	________

11. What type(s) of power are you using for these pump(s)?

Type of Power		Cost of Power Source
Electric	________	________
Gas engine	________	________
Diesel engine	________	________
LPG engine	________	________

Cost includes ____

12. During the last 15 years, in which years did you irrigate any land on this farm?

1963	________	During which years prior to 1963 did you irrigate?
64	________	____________________
65	________	____________________
66	________	____________________
67	________	____________________
68	________	
69	________	
70	________	
71	________	
72	________	
73	________	
74	________	
75	________	
76	________	
77	________	

13. How many different fields did you irrigate during 19__? ________

19__? ________

For each field, in any year where yield data is available, complete a field form.

(Ask this question last)

14. This question is being asked for a research project regarding the supply of land.

How many acres have you cropped in the last 10 years?

1967	________	acres	1973	________	acres
1968	________	"	1974	________	"
1969	________	"	1975	________	"
1970	________	"	1976	________	"
1971	________	"	1977	________	"
1972	________	"			

Year ________

Field Identification ________________

*Signifies key questions which must be answered for each field and each year. Other questions need not be asked for all years.

1. How many acres are in this field? ________ acres

* 2. How many times did you irrigate this field during 19__? ________

* 3. What were the approximate dates of these applications? and
How much water did you apply each of the times you irrigated the field?

Date	Amount Applied

[If respondent is unable to give dates, get the information separately for June, July, and August.]

4. What would you estimate as the total manhours of labor required to irrigate this field during 19__?

__________ manhours - per day x ________ days per application
per application x ________ applications

or __________ manhours - Total time spent irrigating

* 5. What do you estimate the fuel costs of pumping water for irrigation were? $________ or ________ gal. of ________ or ________ gals./hour
________ hours/revolution

6. a. How much fertilizer did you apply to this field during 19__ (excluding fertilizer applied through the irrigation system)?

__________ lbs.

b. What was the analysis? ________ N ________ P ________ K

(interviewee may also list lbs. of N, P, and K applied).

7. Did you apply any fertilizer through the irrigation system?

yes ________

no ________

a. How much? ________ lbs.

b. What was the analysis? ________ N ________ P ________ K

8. Did you apply any lime during 19__? ________ yes How much? ________
________ no

9. Did you apply any insecticides or herbicides during 19__?
________ yes What were they? How much did you apply?
________ no

Product Applied	Amount

10. How would you describe the soil on this irrigated field? (especially the texture) ______________________________

____

* 11. What crop or crops did you grow on this field? ____________________
If more than one, how many acres were in __________ (crop)? What was your yield in 19__ from this field?

Crop	Acres	Yield

I would now like to compare crop yields and costs of production of an irrigated field with a similar field that you did not irrigate.

12. Do you have any fields adjacent to this field (or at least near this field) that were not irrigated on which you grew ______________?
________ yes Skip to Question 13
________ no Ask Question 12a.

12a. Was this particular field planted to ____________ (same crop) and grown without irrigation within the two years of 19__?
________ yes
________ no → Skip to Question 15

* 13. What was the yield of ____________ (crop) from this field in 19__?
__________ bu./acre

14. Does this adjacent (nearby) field have the same soil type as the irrigated field we have been talking about?

    ________ yes

    ________ no How do the two fields differ? ____________________

    ____

15. Were there any unusual losses to insects, weeds, or diseases on either of these fields?

		Irrigated field	Unirrigated field	
Losses to:	insects			bu/acre
	weeds			bu/acre
	diseases			bu/acre

* 16. Were there any other special circumstances that affected your yields in 19__?

    ________ yes Specify ____________________________________

    ________ no ____________________________________

* 17. Did you plant the same variety in this field as in the irrigated field?

    ________ yes

    ________ no

    If not, which variety did you plant in the irrigated field? __________

    In the unirrigated field? __________

For the last part of this questionnaire, I would like to obtain some information concerning differences in the variable costs of farming irrigated versus unirrigated fields.

18. What would you estimate your maintenance and repair costs were for machinery and equipment associated with irrigation? $__________

19. Were the costs of any other operations increased due to irrigation?

	With irrigation	Without irrigation
Fuel costs	________	________
Fertilizer costs or lb. of fertilizer	________	________
Pesticide costs	________	________
Drying costs	________	________
Miscellaneous costs (specify)	________	________

Are these costs per acre _______? or per field? (_______ acres)

Year	Field	Crop	Irrigated Yield	Unirrigated Yield	Other Information:[1]	No. of Applications in: June	July	Aug.	Other	Amount per Application
19__										
19__										
19__										
19__										
19__										
19__										
19__										

[1]Other information should include: 1) varietal differences, 2) unusual losses to pests and 3) special circumstances affecting yield that year.